Reforestation Practices for Conifers in California

Technical editor: William Stewart, University of California, Berkeley. 2020

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Forward

The inspiration and impetus to finally develop this new publication documenting the latest reforestation practices for conifers in California came from several directions. In 1979, far-sighted reforestation professionals held the first Forest Vegetation Management Conference (FVMC). This organization fostered the exchange of ideas and information that played a central role in the significant improvements in reforestation practices used in California and elsewhere over the past 40+ years. With many key practitioners on the cusp of retirement, a sense of urgency to share their mostly unpublished knowledge led to the creation of the FVMC Forest Legacy Committee. The consequent development of this publication is a major addition to the legacy of this organization and its ongoing efforts.

Among the many individuals who contributed inspiration and guidance to this effort, the late Dr. Robert Powers deserves special recognition. He spent many years as a soil scientist and silviculturist with the USDA Forest Service's Pacific Southwest Research Station in Redding, California. Bob Powers had that almost unique ability to look into the future and determine what questions practitioners of forest management would like answered, and then design applied research that would provide those answers. His presence is sorely missed.

Another incentive to develop this publication came from an unlikely international source: the Association for Forests, Development, and Conservation (AFDC) of Lebanon. The AFDC was formed in 1993 to promote reforestation, fire-fighting and conservation work after a series of severe wildfires. Two of this publication's authors, Bob Rynearson and I, have provided assistance to AFDC's reforestation efforts since 2010 and were inspired by the efforts that the group made to publish reforestation guidance for their country. Thus, we became motivated and felt compelled to begin this long overdue effort in California, another place with a challenging Mediterranean climate.

Tom Jopson, Chair
Forest Legacy Committee
Forest Vegetation Management Conference

Acknowledgments

The Forest Vegetation Management Conference (FVMC) made major contributions to both the accumulation of the new knowledge that led to the creation of this book and the process that led to this book becoming a reality rather than just an idea. This is the peer reviewed version of an upcoming UCANR print and digital publication that is in the editing and production process. The reforestation needs on the forests impacted by wildfires over the past five years demands that we get this new information into the hands of practitioners as soon as possible.

Since 1979, these 40 individuals stepped up to serve as chairpersons of the FVMC, which was a four-year term of service as officers of the organization:

> Len Lindstrand (W.M.Beaty & Associates), Mike Srago (USDA Forest Service), Charlie Brown (Fruit Growers Supply Co.), Tom Robson (UC Cooperative Extension), Phil Aune (USDA Forest Service), Jim Rydelius (Simpson Timber), Dave Thomas (USDA Forest Service), Jeanne Tomascheski (Santa Fe Pacific Timber Company), Dan Coombes (Soper-Wheeler Company), Franklin Burch (USDA Forest Service), Tom Nelson (Sierra Pacific Industries), Duane Nelson (USDA Forest Service), Tom Simonson (USDA Forest Service), Kimberly Rodrigues (UC Cooperative Extension), Robert Brenton (Brenton VMS), Joe Sherlock (USDA Forest Service), Mike Landram (USDA Forest Service), Stuart Gray (Churn Creek Veg Management), Ed Fredrickson (Roseburg Resource Co.), Mike Rutty (USDA Forest Service), Randy McDaniel (Sound Forest Technologies), David Bakke (USDA Forest Service), Keith Greenwood (Sierra Pacific Industries), Lee Hazeltine (Precision Applicators), Paul Ederer (Campbell Timberland Management), Danielle Lindler (Jefferson Resource Co.), Kelly Fredrickson (Falling Leaf Services), Jason Warshawer (Roseburg Resource Co.), Dan Blessing (USDA Forest Service), Dave Gallagher (Total Forestry), Tom Young (Fruit Growers Supply Co.), Ken Fleming (Sierra Pacific Industries), Bruce Barr (Sierra Pacific Industries), Bryan Taylor (Sierra Pacific Industries), Scott Carnegie (W.M. Beaty & Associates), Mark Pritchard (Crane Mills), Scott Worden (Soper-Wheeler Co), Matt Brown (PG&E), Brian Lindstrand (Sierra Pacific Industries), Dana Walsh (USDA Forest Service).

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William Stewart accomplished the difficult task of blending the work of 16 authors (many of them non-academic practitioners) and 37 reviewers into a single consistent manuscript while satisfying the sometimes mysterious publication requirements of UCANR. Sari Sommarstrom deserves special recognition as the “Chief Nag” without whom it is unlikely that the project would have been completed in this, or possibly the next, decade. This project was financially enabled through the significant in-kind contributions of many of the authors as well as by direct contributions to the FVMC. The US Forest Service, Sierra Pacific Industries, UC Cooperative Extension and W.M Beaty Associates provided major in-kind contributions by expediting work on the project by their employees. Direct funding was appreciatively received from: State of California-CALFIRE; USDA Forest Service; Growpro, Inc-Cal Forest Nurseries; The Forest Foundation; Roseburg Resources; and Campbell Timberlands.

Cover Photo by Mark Gray

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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.

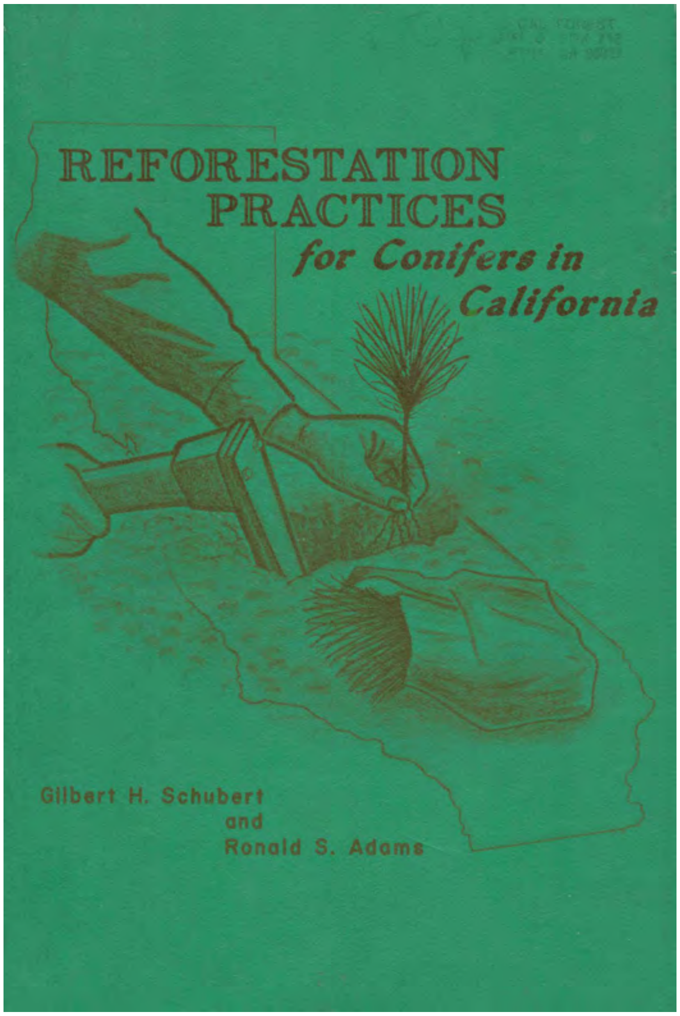

Figure 1.1 The original cover of 'Reforestation Practices for Conifers in California' (1971).

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.

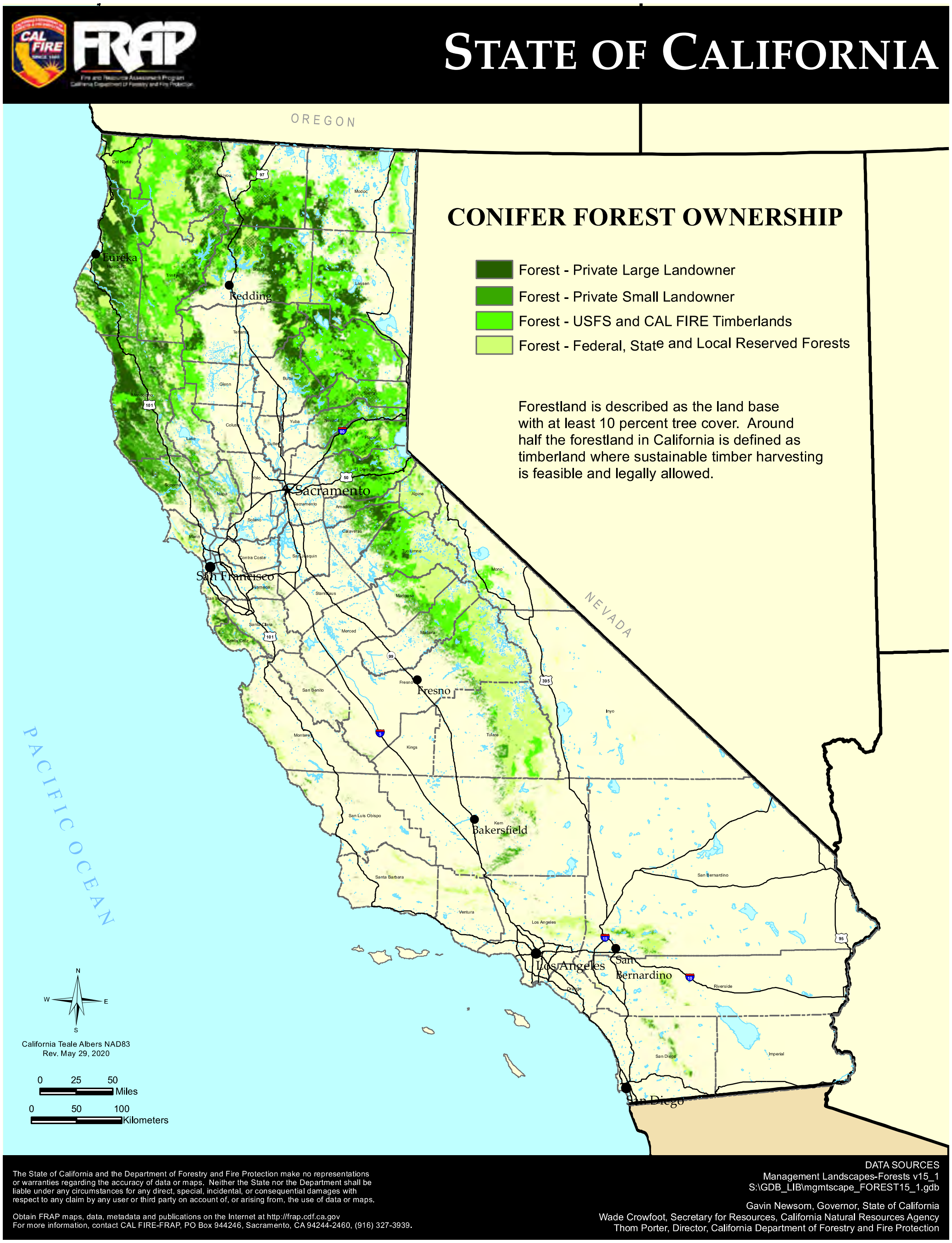

Figure 1.2 Private and Public Conifer Forest Lands in California. *Source*: (Fire and Resource Assessment Program, 2018).

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.

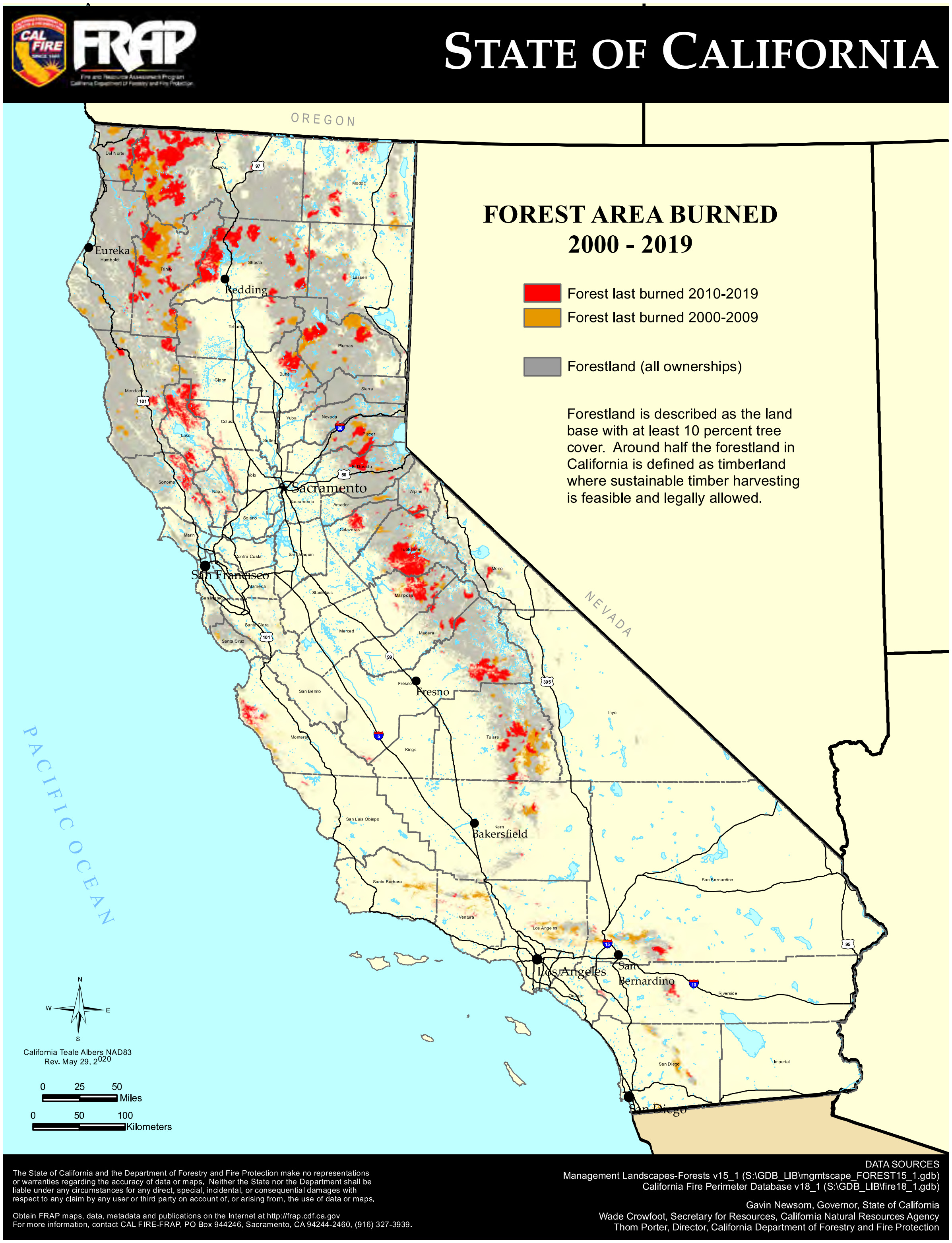

Figure 1.4 Fire Perimeters: Wildfire Perimeters and Forests 2000- 2019.

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.

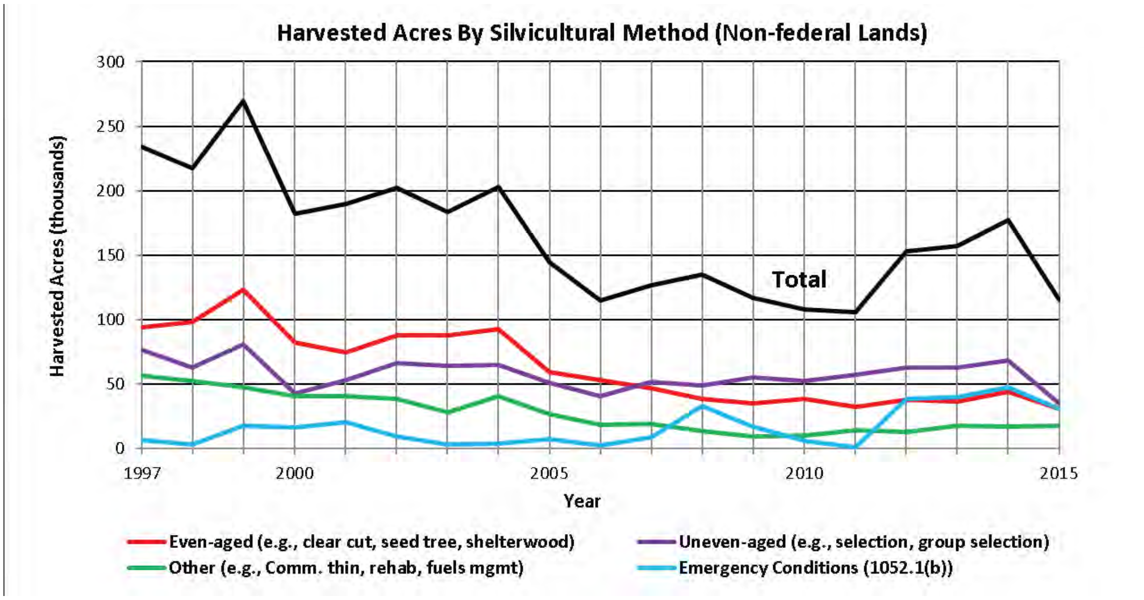

Figure 1.6 Potential Reforestation Acreage on Private Lands, 1997-2015 (CDFFP 2018). *Source*: (Fire and Resource Assessment Program, 2018).

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).

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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.

Chapter 2:
Investing in Reforestation

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Why Invest in Reforestation?

Decades of experience have proved that successful reforestation can not be done inexpensively but it can be done cost-effectively. California has significant challenges to successful reforestation due to competing vegetation, hot summers, snow and frost, and many varied agents that can damage or kill seedlings. The necessary planning, implementation, and monitoring costs stretch out over years and the revenues and other future benefits rarely occur in the first one or two decades when the investments must be made. Experience has generally shown that the full costs of not completing reforestation may be greater than the costs of not undertaking the necessary reforestation steps. In addition to the benefits of a sustainable stream of renewable wood products, young forests also provide important early seral stage wildlife habitats, vegetative biodiversity, greater carbon sequestration rates and numerous aesthetic benefits that exceed those of most brushfields or fields of invasive or exotic plants.

The focus of this chapter is on the investment decision and actions that landowners of all types will need to consider as they embark on any reforestation project. While the financial returns from any individual reforestation projects will be decades out, ensuring that forests maintain their productivity is essential to the long term viability of sustainable forestry enterprises. The numerous public benefits that come from successful reforestation investments are key justifications for federal and state governments to provide technical and material assistance, federal and state cost-share programs, and favorable tax considerations for reforestation expenses. Greater public support for reforestation on both private and public forest lands can substantially improve the overall rate of successful reforestation in California by reducing the immediate financial hurdles that can impede action. The chapter will go over the key steps of a reforestation project undertaken by private landowners or public agencies. While the mix of private and public financing will vary for different projects, having a clear view of the costs and benefits will be critical to get the relevant decision makers to support investing in reforestation. The key steps include estimating costs of different packages of actions and the management and planning required, estimating potential revenues and non-economic benefits, conducting a systematic economic analysis that integrates the costs and benefits that occur across decades, and finally developing an operational plan.

Estimating costs and revenues

The first step in financing reforestation is estimating the potential range of project costs that must occur decades before any revenue from newly planted trees. The total costs will depend on how many acres will be reforested, how much emphasis is placed on forest growth rather than simply forest cover or vegetation cover, what treatments are chosen, how challenging the site is, and what logistical efficiencies can be achieved. Larger organizations will typically have experiences and costs for similar recent projects that they have recently completed. Forestry consultants and landowners with more limited recent reforestation experience should consult with local experts and review the reimbursable cost rates assembled by the USDA Natural Resource Conservation Service (NRCS) and Calfire's CFIP for their cost-share programs to develop their initial estimates of their potential project costs. After developing a reasonable estimate of the projected reforestation costs for a project, the next step is to assess the potential financing options. Finally, landowners should also consider when future revenues will eventually be produced from the reforested sites.

Assessing financing options

How reforestation projects are going to be financed varies considerably across owners. Large forest landowners and owners of investment properties typically treat reforestation as a long-term investment in a sustainable business that is judged by comparing the value of future returns to the more immediate costs that must be undertaken to bring seedlings to an age where they can be profitably and sustainably managed. Each individual project need not undergo a detailed economic analysis if the owners are invested in long term character of their forest enterprise and have confidence that their standard procedures have been proven to be cost-effective. Although it is rarely possible to borrow against future revenues to finance immediate restoration expenses, it is worthwhile to consider the potential future revenues related to healthy and growing stands that could come from new products and ecosystem services such as mitigation credits for certain habitats, conservation easements, recreational leases, and climate benefits.

Long term investments on private lands will be taxed as capital gains rather than the usually higher ordinary income tax rates. Tax rules that allow initial costs to be immediately deducted rather than amortized over a number of years vary for different types of private owners and can reduce the overall cost of a project. The rules can change with revisions to the federal tax codes, so it is important to consult the most recent official information on taxation relating to forestlands. In addition there are also a number of federal and state cost-share programs that are available mainly for small landowners. Finally, accessing publicly maintained resource such as seed banks or University based technical assistance that often provide services to landowners at less than full cost can also be used to create a more favorable financing package for private landowners.

Unexpected mortality event and reforestation needs after severe wildfires can place severe financial constraints on landowners. Landowners may have also experienced significant financial losses to their residences and other assets within the fire. Small diameter trees burned in a wildfire have little value and it is often very difficult for smaller landowners to contract with loggers for salvage harvesting. After large wildfires, it is common for the limited number of loggers in a region to be contracted by the larger private forest owners. Delays in initiating reforestation projects or choosing more expensive reforestation practices can severely limit the number of successfully reforested acres that landowners with limited budget can undertake. Because smaller properties often lack the ability and economies of scale necessary to capture the financial value in fire damaged stands, they often rely on governmental technical assistance and cost share programs to assist with successful reforestation projects.

The USDA Forest Service explicitly defines a broad range of non-economic goals for reforestation on National Forest lands. Federal Environmental Quality Improvement Program (EQIP) cost-share payments also consider the non-economic benefits of successful reforestation. Understanding and properly accounting for these non-economic benefits will be important in getting federal funding for reforestation efforts. After applying consistent values to desired non-economic and economic outcomes, the use of standardized economic analysis tools can help identify the projects that will deliver the best outcomes given budget constraints.

On National Forest lands, the Forest Service was historically able to finance much of their reforestation by reinvesting a portion of the timber revenues into regenerating the forest. Current federal funds for USFS reforestation projects now come mainly from the Vegetation and Watershed management program and the Reforestation Trust Fund (USDA 2018). The large increases in wildfire damage on Forest Service lands in California has not been matched by an increase in successfully reforested areas and is leading to a growing backlog of area in need of reforestation.

Tax treatment of private reforestation investments – deduction, amortization, and cost-share payments

The tax treatment of reforestation investments depends on the purpose of the investment (personal enjoyment, investment, or business), the ownership structure (small family ownership, commercial timber business, partnerships, trusts, etc.), and any changes in federal and state tax law. As of 2016, small landowners could deduct up to $10,000 per year for reforestation costs while larger expenditures would have to be amortized over 84 months. Larger landowners can deduct some of their reforestation costs if they are closely related in time and purpose to revenue generating harvest events. Unexpected costs related to declared disasters such as severe wildfires are treated more favorably. Some cost share payments from certain defined federal and state programs can be excluded from reported income. Reforestation activities that are undertaken as part of a federally funded conservation activity may not be counted against the overall caps on reforestation costs. Landowners should discuss their plans with their local Natural Resources Conservation Service (NRCS) staff to understand the potential tax implications. Given the large expenditures required for reforestation and the technical details of specific cases, it is always important to consult timber and forest taxation specialists who are up to date on current policies. (Greene et al. 2012, National Timber Tax Website 2019, Wang 2019).

Post wildfire loss responses of small landowners

One of the fastest growing needs for reforestation in California is after California's increasingly common severe wildfires. These fires often destroy the majority of the timber value as well as damage public benefits such as diverse wildlife habitats, erosion protection, and carbon sequestration by these forests. There are numerous public and private benefits that can come from successful reforestation projects in addition to the financial benefits of reforestation. Owners of smaller forested properties often place less emphasis on future financial returns of forestry compared to other benefits from their forest (Ferranto et al. 2011). Management activities that improve wildlife habitat and forest health are the most common activities across family ownerships of all sizes (Stewart et al. 2012) and should be considered as important benefits when planning reforestation projects.

The complexity and high costs for many small landowners can limit the level of forest restoration after wildfires if they can not quickly access technical and financial resources. A recent study of family forest owners whose properties burned in a 2014 wildfire in the central Sierra Nevada provides insights into the goals and challenges for owners of smaller properties who want to reforest their land (Waks et al. 2019). The study noted that "All [landowners] wanted to reforest, but a third would not have without the free reforestation program offered by the local resource conservation district to mitigate climate change through increased carbon sequestration. The rest of the landowners would have tried to do the work themselves or pursued other programs despite complicated logistics and high upfront costs." (Waks et al. 2019). Economic analyses for programs designed to assist smaller landowners should also consider the non-timber benefits that accrue to the owners as well as the social benefits of successful reforestation of sites that otherwise would often revert to brushfields in many parts of California. Access to well-funded state and federal cost share programs will be an increasingly important component of a successful reforestation strategy at a statewide level in California.

State and Federal Cost-Share Programs

To help landowners who lack the needed financial and technical resources to undertake reforestation, CAL FIRE and the USDA Natural Resources Conservation Service (NRCS) both offer cost-share programs for reforestation projects. The full suite of activities covered in this reforestation publication may be eligible for cost-share funding. It can be challenging to keep up with the latest requirements or understand the application processes, especially for landowners suffering the many consequences of a high severity wildfire. Financial assistance programs continually change and are subject to swings in government policy priorities and budgets, so it wise to check with the agencies on the current guidelines and funding.

Landowners, and professionals working with them, should check the most recent program details on the CAL FIRE and NRCS websites and with agency staff to help ensure a reforestation project's funding needs can be supported as well as well timed. Specific activities have different reimbursement schedules based on a number of factors. The level of cost-share, for example, can be higher for reforestation activities after disasters such as wildfires and severe insect mortality. The federal Farm Service Agency's Emergency Forest Restoration Program (FSA EFRP) is another program that uses EQIP practices and payment rates. It is important to understand that grants only reimburse the recipient after project expenses, and reimbursements are limited by the applicable cost share rates and the most recent reimbursement schedules. As a matter of standard practice, the federal or state programs do not offer payment in advance but EQIP has provisions for contract waivers that need to be approved in advance on a project by project basis. Calfire's CFIP program also has the potential for loans that can be made to clients implementing projects. Matching a landowner's objectives and needs to the appropriate cost-share program is an important consideration in selecting which program to pursue. Forest management plans are also required for each of the cost-share programs.

California Forest Improvement Program (CFIP):

This long-standing state grant effort has a stated purpose "to encourage private and public investment in, and improved management of, California forest lands and resources." Cost-share assistance of up to 75% of project costs is usually available to private and public ownerships containing 20 to 5,000 acres of forest land. A 90% rate currently applies to lands substantially damaged by fire, insects and disease, for all Cooperative Forest Management Plans, and for lands with less than 500 acres of forestland. Consultation with and project supervision by a Registered Professional Forester (RPF) is required with some of the costs covered by the grant.

Funded activities include management planning, site preparation (e.g., mechanical or herbicide treatments), tree seedling purchase and planting, precommercial thinning or release, pruning, forest road repair and upgrading, and other conservation practices. However, paying for seedling restocking requirements after a timber harvest plan (THP) is not allowed. The CFIP website lists the current user guides, requirements, cost share rates, and how to contact a CAL FIRE Forest Assistance Specialist. Available funding has increased over recent decades with more financing, including the Timber Regulation and Forest Restoration Fund (TRFRF) and California Climate Investments (CCI), but future funding levels are uncertain.

CAL FIRE's Forest Health Grant Program

Beginning in 2018, Calfire's new program awards Greenhouse Gas Reduction (GHG) Funds allocated by the legislature for California Climate Investments (CCI) to implement larger-scale projects that seek to:

- Proactively restore forest health to reduce greenhouse gases.
- Protect upper watersheds where the state's water supply originates.
- Promote the long-term storage of carbon in forest trees and soils.
- Minimize the loss of forest carbon from large, intense wildfires.
- Further the goals of the California Global Warming Solutions Act of 2006 (Assembly Bill 32, Health and Safety Code Section 38500 et seq.) (AB 32).

In 2018 California committed to spending $1 billion over five years from the Greenhouse Gas Reduction Fund for forest health, fire prevention, and fuel reduction activities. Reforestation projects are one of the types of projects that can be funded and one where the benefits will continue to grow as the trees grow. Eligible applicants include local state and federal agencies including federal land management agencies (excluding conservation easements), state land management agencies, Native American tribes, private forest landowners, resource conservation districts, fire safe councils, land trusts, landowner organizations, conservation groups, and non-profit organizations.

To be eligible for funding under CAL FIRE's Forest Health Grant Program, projects must:

- Focus on large, landscape-scale forestlands composed of one or more landowners, which may cover multiple jurisdictions. Large landscapes usually mean sub-watersheds, firesheds, or larger logical management units. (Includes projects of 10,000 acres or more.)
- Generate a net increase of on-site carbon storage over no project as calculated by the California Air Resources Board's California Climate Investments Quantification methodology.
- Be designed to ensure the project benefits are as permanent as possible.

NRCS's Environmental Quality Incentives Program (**EQIP**)

The EQIP program is designed to support various reforestation activities through several funding "pools", such as Catastrophic Fire Recovery, Tree Mortality, or Forest Health pools. Funding can be provided for many reforestation practices, including site preparation, seedling planting, and post-planting weed control (Natural Resources Conservation Service 2020). EQIP payments made to clients are fixed rates, meaning regardless of actual cost paid by a client to a contractor to complete work, the payment made by EQIP is fixed. NRCS pays a fixed rate to clients completing reforestation practices, usually intended to provide approximately 50-75% percent of the actual costs. Payment rates to clients can be higher for post-wildfire efforts. A forest management plan is required and can be partially financed as part of NRCS's Conservation Plan assistance.

The stated goals of the EQIP funds include wildfire reduction, forest health improvement, erosion control and water quality protection on working lands. The funding priorities are determined by the Farm Bill that was most recently reauthorized by Congress in 2018. It currently includes reforestation and fuel reduction. There is no parcel size limitation in EQIP. NRCS also delivers conservation technical assistance through its voluntary Conservation Technical Assistance Program (CTA) and has foresters on staff in some county offices as well as in the state office. The CTA, or your RPF, can assist with the EQIP application.

Generalized 2019 Reforestation Costs for Federal and State Cost Share Programs

The following table provides a summary of the generalized cost reimbursement range for different practices from the most recent cost-share programs of NRCS and Calfire's CFIP. The more extensive full list of treatments and reimbursement rates are available at the respective websites.

Table 2.1 Generalized Cost Range for Reforestation Costs for Cost-Share Programs in California

		NRCS	NRCS	CALFIRE	CALFIRE
NRCS EQIP # or CFIP	**Practice**	**Low $/acre**	**High $/acre**	**Low $/acre**	**High $/acre**
490	Tree/shrub site prep	100	1000	350	800
612	Tree/shrub establishment				
612	without browse protection	300	500	225	550
612	with browse protection	500	800	575	900
314	Brush Management			350	800
314	mechanical	200	400		
314	hand	30	500		
314	chemical	30	100		
315	Herbaceous Weed Management			250	750
315	mechanical	70	1000		
315	hand	200	300		
315	chemical	30	200		
338	Prescribed Burning	10	130		
CFIP	Pre-commercial thinning			350	700
CFIP	Pruning			350	450
CFIP	Mechanical Release			350	800
CFIP	Other Release Treatment			250	700
CFIP	Follow-up			400	1000

Source: (California Department of Forestry and Fire Protection 2019, Natural Resources Conservation Service 2019).

Some of the key points from the comparison of federal and state cost estimates are the different ways that the federal and state programs define reimbursable treatments, the wide range between low and high cost per acre estimates for all activities, and the lower range of estimated costs for site preparation treatments compared to post planting mechanical release and other release treatments. The forester or landowner submits their cost estimates but maximum reimbursement rates are fixed by federal and state regulations. Landowners will have to finance the difference between the actual costs and allowable reimbursements. In general, smaller projects will often have costs per acre due to the lack of economies of scale. Within the site prep treatments, chemical treatments for controlling competing vegetation are estimated to be more economical than mechanical or hand treatments. Prescribed burning reimbursement rates suggest that such treatments can be economical compared to other methods. In many cases, Calfire permits are required for prescribed fires on private lands and they often will provide some of the necessary fire protection resources.

Comparison of Two Programs

The following table summarizes the major differences between two popular state and federal cost-share programs for individual landowners: CFIP and EQIP.

Table 2.2 Comparison of CAL FIRE's CFIP and NRCS's EQIP Programs

Criteria	CAL FIRE'S California Forest Improvement Program (CFIP)	NRCS's Environmental Quality Incentive Program (EQIP)
Ownership Size	20 acres. Maximum of 5,000 acres. Forestland is 10% or more cover including oaks.	No minimum or maximum size. Management can be limited to improving forest health or initiating restoration. Forest management does not require explicit plans for future timber harvests. Must meet the federal definition of non-industrial forest land.*
Zoning	Must be zoned to allow forest management, via Timber Production Zone or other Land Use Addendum.	N/A
Maintenance	Projects must be maintained for at least 10 years.	Maintenance of project varies by activity projects must be maintained for practice lifespan (variable).
Covered activities	Preparation of management plans, RPF supervision, site preparation, planting, pre-commercial thinning, pruning, release treatments, slash disposal.	Preparation of management plans, brush management, herbaceous weed treatment, prescribed burning, woody residue treatment, fuel breaks, tree/shrub site preparation, tree establishment, forest stand improvement, and forest road and trail erosion control.
Activity Size	5 acres minimum, for forest management. No minimum on habitat improvement.	NRCS staff may also provide a forest management plan (FMP) for smaller size projects
THP Work	Will not cover THP stocking requirements.	Does not pay for work to be planned or implemented in a THP.
Pre-Qualify	Pre-review with Cal Fire Forester.	All projects are based on submitting applications.
Management Plan Requirements	A plan is required, Cal Fire will fund. The plan must be done before doing any work.	Forest Management Plan is required for all forestry projects. Funding may cover plan cost if requested and receives priority for funding in some cases.
Supervision	RPF supervision required & funded.	No requirement for supervision, but clients are recommended to hire RPF for supervision of field work, use a qualified contractor to do the work, and a Pesticide Control Advisor (PCA) report is required for all projects which involve use of herbicides..
Funding Rates	For live tree/green projects 75% of expense to maximum in contract. For substantially damaged lands 90% cost share activities over following 10 years.	Fixed rate paid to clients for completed work, to cover about 50-75% of actual costs. Rate can be higher for post-wildfire efforts.
Available Funds	$3+ million from TRFRF, with considerable additional funding from CCI after 2018.	Forestry fund allocates $5-10 million per year for highest ranking projects.

Fund Timing	First come, first served. Budget year is July through June.	Applications accepted continuously; ranking and funding occurs 3-4 times / year.
Payment by Activity	Interim payments allowed.	Interim payments allowed.
Proof of Payment	Proof of payment to contractors required before payment to landowner.	Practice must be field certified by NRCS staff & meet requirements and specifications prior to payment.
Adjusted Gross Income (AGI) Cap		AGI > $900,000 is ineligible.

**Federal definition of "non-industrial forest land" is "rural land that has existing tree cover or is suitable for growing trees; and is owned by any nonindustrial private individual, group, association, corporation, Indian Tribe, or other private legal entity that has definitive decision-making authority over the land."*

Getting Additional Help

Some owners of smaller parcels may find the cost-share process too time-consuming or intimidating to undertake by themselves, especially following the trauma of a catastrophic event. Having a local organization, such as Resource Conservation District (RCD), create a cooperative program offering reforestation assistance to all small landowners can reduce financial and technical barriers and allow for more overall acres to be reforested. After the 2014 King wildfire in the central Sierra, owners of nonindustrial forest land whose properties were burned participated in an innovative and positive program offered by the local resource conservation districts. The district contracted with a RPF and with crews to carry out the project.

Estimating potential revenues

A business challenge of reforestation is that potential future revenues will not come for decades when the future prices of both traditional products such as sawlogs and potential new products and services are hard to predict. While timber revenues from mature trees will usually be the main source of value, hunting or other recreation-oriented leases can become more valuable with increasing forest cover and generate future cash flows. In addition, new services such as conservation easements, habitat mitigation credits, and forest carbon offset credits may also develop into value. Since the potential revenue from this innovative services is somewhat speculative and may involve considerable transaction costs, a conservative estimation method is to initially focus on potential timber revenues and assume that future prices and revenues will be similar to the current or recent prices. Potential timber revenues can be estimated from a combination of forest models of biological growth and available information on historic and current price trends. Once a baseline analysis is completed, it is easier to assess different scenarios with different price and products.

Reforestation investments based primarily on future timber revenues benefit from a good understanding of how timber prices are calculated and vary by region, species, harvest method, and the overall size of the harvest. The most comprehensive timber values available to the general public are the harvest values published by the California Department of Tax and Fee Administration (CDTFA) that took over some of the timber tax activities that had historically been undertaken by the California Board of Equalization (BOE). The timber harvest values in California are tied to the stumpage value of the unharvested trees rather than the delivered 'pond values' published for Oregon (Oregon Department of Forestry 2020). In California, the stumpage value is calculated as the final product value minus harvest, transportation, and processing costs. In California, the harvest values that are the basis for timber taxation are published twice a year for nine different regions of the state. The published timber harvest values are in dollars per thousand board feet (Scribner mbf) that is the standard unit of harvest measurement in California. The 'Hem/fir' species group includes white fir, red fir, grand fir and the hemlock and has no price differentiation based on volume per log. The size code captures any price premium for larger logs measured in board feet per log. A size code 2 log containing 200 board feet per log means that five logs are needed to make up one thousand board feet (mbf) that is the basis of the values listed in the tables. Timber value areas where there is a N/A value for a species means that little or none of that species is purchased and milled in that region.

2019 Stumpage Values

TABLE G – GREEN TIMBER HARVEST VALUES - This table shows the harvest values for timber by species, size, and timber value area. The taxpayer makes the adjustments for the logging system, for small total volume on the harvest operation, and low volume per acre on the harvest operation.

GREEN TIMBER

Tractor Logging (Logging Code T)

SPECIES	SPECIES CODE	VOLUME PER LOG	TIMBER VALUE AREA									
			SIZE CODE	1	2	3	4	5	6	7	8	9
		Over 300	1	160	160	60	140	250	220	240	190	140
Ponderosa Pine	PPG	150-300	2	120	150	50	120	230	200	200	170	120
		Under 150	3	80	90	30	100	210	180	190	160	110
Hem/fir	FG	N/A	N/A	120	60	N/A	150	240	180	210	140	100
		Over 300	1	260	240	60	280	390	220	350	320	N/A
Douglas-fir	DFG	150-300	2	250	210	50	270	380	210	330	300	N/A
		Under 150	3	240	200	30	260	370	200	310	290	N/A
Incense Cedar	ICG	N/A	N/A	100	130	N/A	260	350	320	370	330	160
		Over 300	1	950	1000	960	N/A	N/A	N/A	N/A	N/A	N/A
Redwood	RG	150-300	2	930	880	820	N/A	N/A	N/A	N/A	N/A	N/A
		Under 150	3	830	830	780	N/A	N/A	N/A	N/A	N/A	N/A
Port-Orford Cedar	PCG	Over 125	1	300	N/A	N/A	300	N/A	N/A	N/A	N/A	N/A
		125 & Under	2	200	N/A	N/A	200	N/A	N/A	N/A	N/A	N/A

Figure 2.1 Green Timber Harvest Value Schedule from the CDTFA July-December 2019 Schedule.*Source:* (California Department of Tax and Fee Administration 2019) https://www.cdtfa.ca.gov/taxes-and-fees/timber-tax.htm.

In general, regions with many competing sawmills have higher prices than regions with fewer mills. As shown in figure 2.1 for CDTFA green timber stumpage value chart for the July-December 2019 period, there is also a slight premium for larger logs in California and for sales that contain more logs. The stumpage value is also reduced for more expensive logging systems, smaller total sale volumes, and lower volumes per acre. In the event of a future major mortality event such as a wildfire, the salvage value of Ponderosa Pine logs is estimated to decrease by more than half, with lesser reductions for other species.

Price Trends for Green Tree Stumpage Values in California 1977-2019

Since the mature trees will eventually be valued after many decades, it is worthwhile to consider what recent price trends have been and what this suggests for future prices. Because the most recent prices by species and by log size when the reforestation project is planned and implemented are not necessarily the most accurate prediction of the future harvest values, reforestation project planners must make their own estimates of the future harvest values for seedlings that will not be harvested for decades. Figure 2.2 shows the trends in stumpage values by species in the Shasta County, California region (with the redwood prices from Humboldt County) from 1977 to 2019. It is important to note that the prices for fire-damaged trees are lower and calculated separately by the California Department of Tax and Fee Administration.

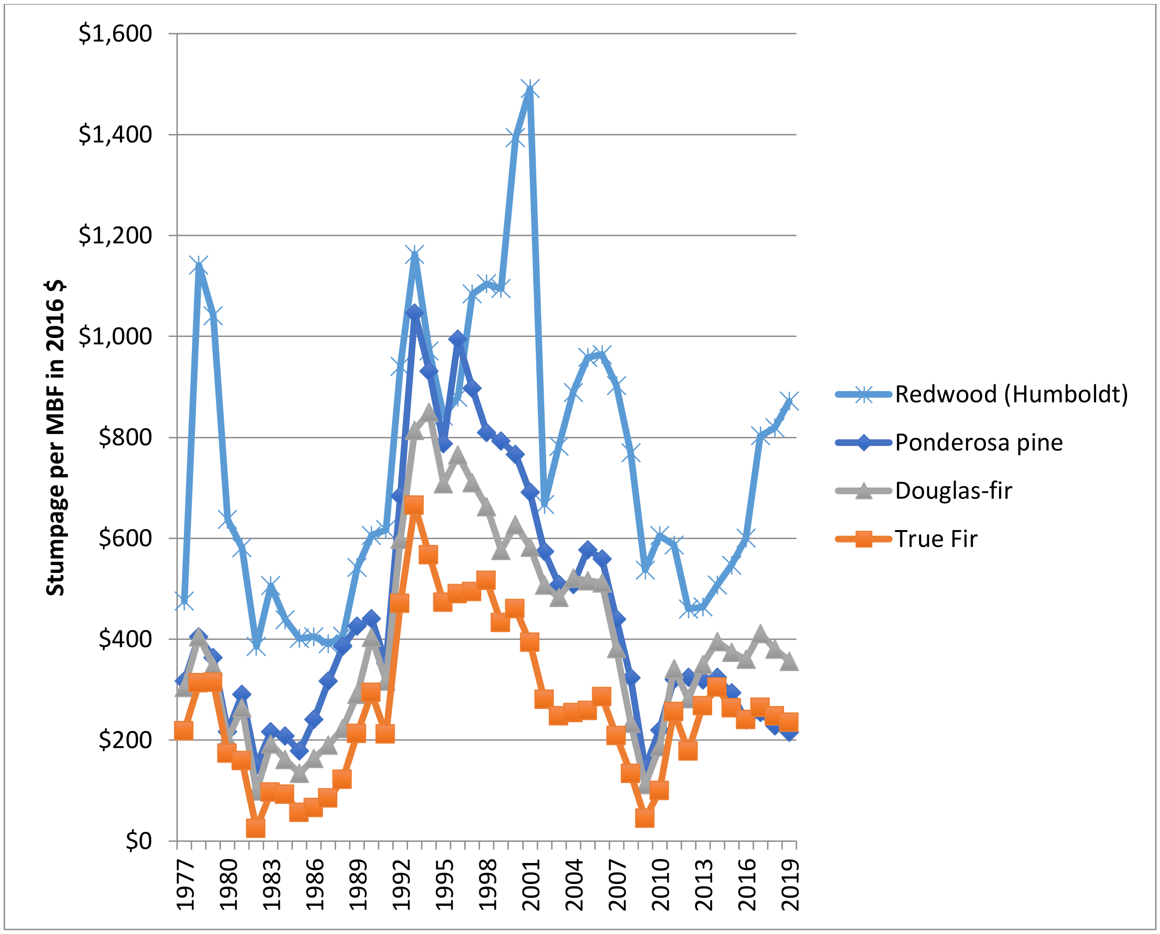

Figure 2.2 Inflation adjusted stumpage price trends for major species in Shasta County, California.*Source:* CDTFA green timber harvest values.

The most noticeable pattern over time is the high variability of prices from year to year as well as between species. Prices climbed rapidly after the 1983 recession and continued to increase until the large reduction in home building following the 2008 recession. Since then, prices have stabilized in a historical context but remain volatile. Douglas-fir, pines, and true firs are the three most significant species by volume harvested. The most significant trends over the past few decades has been the decline in what had been a significant price premium for pine, and the relative increase in the value of true fir species. Since most of the trees planted now will not be harvested for 40 years or more, it is difficult to predict future prices accurately. A reasonable economic strategy, beyond planting the highly valuable redwood in its natural region, would be to diversify by planting a wide variety of species in forest types that historically had those species, so that the drop in price for one species does not create an untenable situation for the landowner.

Basic Economic Analysis Tools for Reforestation

The physiological basis for investing more expertise and money in restoration is the ability to shift more of the total vegetation growth of the site away from shrubs and grasses and towards the well-spaced planted trees. In the Mediterranean climate common in the interior forests in California, small conifer seedlings have a well-documented growth disadvantage compared shrubs for their first decades unless active and successful control of competing vegetation is undertaken (McDonald and Fiddler 2010). This pattern was also well documented across twelve Long-Term Soil Productivity (LTSP) sites in California (Zhang et al. 2017) summarized in figure 2.3. The Y-axis in figure 2.3 below is aboveground biomass in Mg/ha (figures G and H) and trees per hectare (figure I). The X-axis shows the results across three levels of soil compaction (C0, C1, and C2). The light colored bars had no competing vegetation control and the dark colored bars had fully effective vegetation control.

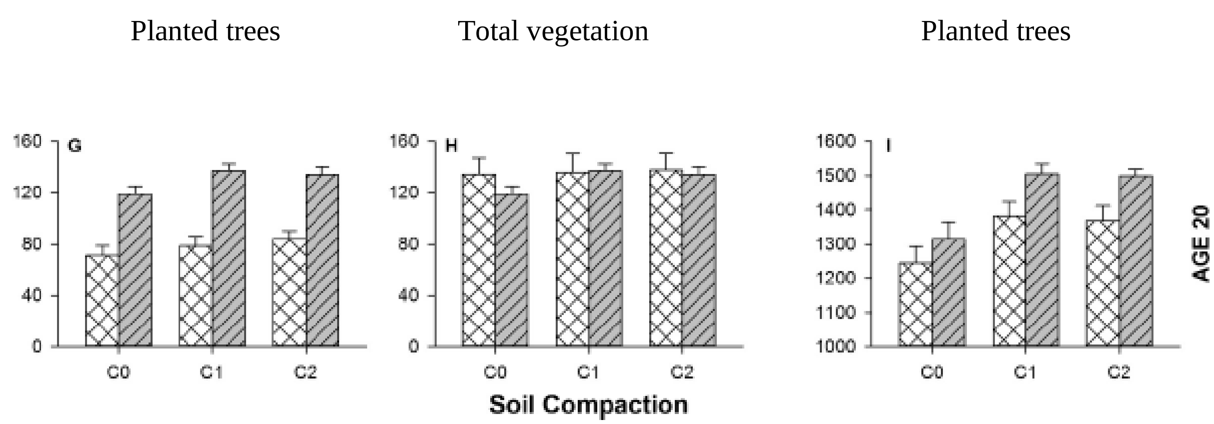

Figure 2.3 Planted tree biomass, total vegetation biomass, and planted trees per hectare for 20 year old LTSP plots in Northern California.*Source:* Zhang et al. 2017, figure 2.

After 20 years, the no vegetation control and full vegetation control treatments had essentially identical amounts of biomass in total vegetation, but the full vegetation control had more than 50% more biomass in the planted conifer trees (Zhang et al. 2017). For our economic analysis of reforestation, we will use a simplified example where increased investment in vegetation control leads to increases of 50% in the eventual commercial harvest volume.

The economics of conifer reforestation projects also needs to compared to other long term investments that private parties or government entities can take. The value growth for both the private benefits and the public benefits of a healthy forest stand will go up based on the stumpage value of the sawlogs, improving recreational and amenity values, and potentially improved grazing opportunities if the understory is grass rather than shrubs. In addition to helping to organize the different steps that need to occur in different years and the timing of various benefits, basic economic analysis tools are often required by private and public funding entities. Forest land investment costs include annual management costs, specialized professional assistance, taxes, fees, as well as the opportunity cost of capital or the direct costs of loans. In California, a very successful reforestation project typically will not produce any net revenue for at least 30 to 40 years, and the full value of the trees will not be realized for 50 to 100 years. Over that period of time, an owner must also consider the usually uninsurable risk of loss from severe wildfires or large insect outbreaks, major regulatory changes, unpredictable future market prices and conditions, and the actual rate of growth of the newly planted forests.

A key for conducting an economic analysis of a major reforestation project is properly accounting for the 'time value' of money. Different alternative investments such as stocks, bonds, or fully liquid cash accounts have very different effective interest rates that are higher for investments that have greater variability and greater risks of very high and very low returns. It is important to also consider if inflation rates are included in prices when considering long term investments. Economists refer to prices that are corrected for inflation over years as 'real' prices (often quoted as dollars in a specific year such as 2016$) and 'nominal' prices as values that may include different levels of inflation.

When conducting an economic analysis over a long time period, it is important to bring all the costs and returns to the same point in time (such as in 2016 $ that are used in the following examples), that they can be accurately compared. If an alternative investment to a reforestation project is estimated to deliver a 5% real rate of return, that means that $1 today will be worth $1.05 next year and $1 next year is only worth $0.95 today. Over time, the effect of an annual interest rate compounds or discounts according to the formulas - Future value = Present value * (1+i)^t and Present value = Future value/ (1=i)^t. For example if you invest $400 in thinning costs today, it would need to increase the forest stand value to $1,355 in 25 years if you wanted to equal a 5% rate of return over the period. When returns are reinvested, the benefits compound so that the relative advantage of higher rates of return is not linear.

For example, if you expect that a precommercial thinning of a reforested stand to increase the diameter at breast height (DBH) from 16" to 22" over the next 35 years to garner the higher value that larger trees often receive, you can calculate how much you could invest now that would be equal to the increased revenue in 35 years. Assuming that the stumpage value of the larger trees would increase from $300 to $400 per mbf in real terms, the additional harvest volume would be 10 thousand board feet (mbf)/ acre, and that your benchmark real interest rate is 5% per year, the breakeven amount you can invest today would be $181 ($1000/ (1+.05)^35 = $181) to justify the investment.

The FORECON financial analysis spreadsheet tool for forestry investments

The FORECON spreadsheet tool that can be downloaded from both the UCANR Forest and the UC Berkeley Forests web sites is a simple tool that allows users to conduct a basic financial analysis of any reforestation project or other forest investments. While the model does not include detailed annual cash flow estimates or tax implications, it does allow the user to quickly assess the overall impact of different cost and revenue assumptions. More sophisticated spreadsheet tools are available and may be necessary to secure external financing, but this model is presented to illustrate the basic concepts with realistic scenarios.

The example we use here is a single acre of a post-harvest reforestation under California's 2019 Forest Practice Rules requirement of planting 200 trees per acre on high site land. We modeled the increased investment in effective vegetation control to mirror the increased tree growth document in the Zhang et al. (2017) article that is referenced earlier. We used recent NRCS EQIP and Calfire CFIP activity costs as well as current stumpage prices for small log and large logs for revenues. In year 1, the operation is planned out before the actual planting and the site prep is done to control competing vegetation. Planting is done in the following year with an additional weed control conducted two years after the planting to ensure the successful release of the seedlings. Finally, a pre-commercial thin is conducted six years after planting to select the desired number, spacing, and and mix of trees species that will be the eventual crop trees for a first commercial thin operation at year 40. We assume that the first commercial only removes the smallest diameter trees with relatively limited stumpage values. We also project the revenue from a final harvest at year 60. As described earlier, we use a discount rate of 5% to account for the 'time value of money'. This means that revenue in later years is calculated to be worth considerably less than the same sum would be worth now. For this scenario we did not estimate any increases in future real prices so everything is calculated in current dollars.

Table 2.3 FORECON model for financial analysis of forestry investments (baseline estimates)

Discount Factor	0.05				
Inflation Rate	0.02				
Real Price Increase	0				
Real Cost Increase	0				
Period of Investment					
	Cost Summary				
				Inflated Cost	Discounted Cost
Item	Year	Cost			
Site Prep	1	200		-200	-200
Planning and supervision	1	100		-100	-100
Prescribed burn	2				
Plant 200 TPA	2	300		-306	-291
Additional weed control	4	200		-212	-183
Pre commercial thin	7	350		-394	-294
Additional brush removal	1				
	Return Summary				
Future/Base $ Ratio	1.0				
Item	Year	Cut (MBF)	Stumpage Price	Inflated Returns	Discounted Returns
Commercial thin	40	4	50	433	65
Final harvest	60	31	250	29,754	1,673
Other items	Year		Actual Price	Inflated Returns	Discounted Returns
CFIP cost share	2		0	0	0
Other revenue					
Other revenue					
Amount of loan	Year of loan	Period of loan	Interest rate	Annual payment	Discounted net value
Present Net Worth (1 investment period)					668
Present Net Worth (infinite investment periods)					1,288

Source: Berkeley Forests website

Comparing baseline and alternative scenarios

In the baseline example we assumed that the site prep step was effective, only one post planting weed control was required and that the later pre commercial thin achieved the desired stand of trees that followed the average growth rate expected by forest growth models. We estimated fairly low prices for the smaller diameter trees that will be harvested during the first commercial thin and moderate prices for the trees in the final harvest. Since we can not accurately predicted timber prices in future decades, the purpose of considering a range of alternative scenarios is to provide guidance on the relative value of different immediate investments. We use four scenarios to illustrate the potential benefits of different approaches to controlling competing vegetation.

1. Baseline scenario with ineffective weed control and no additional brush control (akin to the 'no vegetation control' variants in Zhang et al. 2017).
2. Scenario with similar expenditures but where site prep was sufficient to control herbs, grasses and shrubs.
3. Scenarios with an additional $100/acre for additional investment in brush control, with and without 75% cost share payments from EQIP or CFIP.
4. Scenarios with an additional $200/acre for additional investment in brush control, with and without 75% cost share payments from EQIP or CFIP.

For this example we are assuming that the effective control of competing represents the capture of 100% of the potential benefits measured by Zhang et al. 2017. Scenarios 3 and 4 illustrate the impact of additional expenditures for required shrub control that may be needed on some sites.

The model also makes it simple to evaluate other scenarios such as increased costs to control the competing brush, both with and without 75% cost share payments. Without cost share payments, the additional costs will significantly reduce the present net worth of the project since the costs are immediate but the revenues will only occur many decades in the future. If the project proponents apply for and receive 75% cost share only for the additional brush removal activities, the long term value of the reforestation is protected. In addition to assessing the impact of early reforestation costs and the potential role of cost share payments, the FORECON model can also assess the potential impacts of higher or lower than expected revenues in the future. The change in revenues could be due to differences in growth rates or future prices. If future revenues would only be 75% of what current growth models and prices would suggest, then the financial viability of the project based solely on costs and projected timber revenues would be substantially diminished.

Table 2.4 Estimated per acre costs, revenues, and present net worth for different reforestation scenarios

Tmt #	Treatment	1st decade costs	Estimated intermediate and final harvest volume (mbf)	Present Net Worth (no cost share)	Present Net Worth (75% cost share)
1	Ineffective weed control	$1,069	29	$242	
2	Effective weed control (baseline)	$1,069	41	$1,288	
3	+ $100 additional brush control (if needed to achieve effective vegetation control)	$1,169	41	$1,095	$1,235
4	+ $200 additional brush control (if needed to achieve effective vegetation control)	$1,269	41	$902	$1,183

In all cases, the landowner had to invest over $1,000 per acre in the first decade even though they would not realize significant revenue for 60 years at the first large commercial thin. The estimated present net worth for the total project from site prep to harvest was $242 per acre for the baseline scenario when the control of competing vegetation was not effective. If effective control of competing vegetation could be accomplished with standard site prep treatments without additional expenditures on brush control, the present net worth increased to $1,288 per acre. If additional brush control was required to achieve the growth potential documented in Zhang et al (2017), first decade costs increased and present net worth decreased. When additional treatments were necessary to achieve potential forest growth, 75% cost share payments were effective in assisting landowners in making the significant up front investments necessary to generate long term public and private benefits.

The economic analysis illustrates that importance of controlling initial costs and ensuring projected growth rates for a well-managed reforestation project to achieve a net positive value. The analysis highlights the financial challenges created by the multi decade gap between initial costs and delayed revenues. Additional costs related to more expensive site preparation activities will reduce the present net worth of reforestation to landowners if cost-share programs are not available. If lower than predicted harvest volumes or prices substantially reduce future revenues, they can reduce a reforestation project to a break-even or money losing situation. Without cost share, it is possible that the public benefits accruing from successful reforestation efforts may not materialize if the landowners underinvest in controlling competing vegetation. The spreadsheet tool can also be used to assess the outcome if future intermediate and final yields are higher or lower than the estimated average value, if future prices are higher or lower, or if costs are different for intermediate treatments.

A value of using an economic model is not to develop an accurate estimate of the financial value of a hypothetical investment, but to have a decision support tool to better understand the influence of different specific activities. The long term price trends in California with two crashes and three booms since 1977 makes it very difficult to estimate future revenues accurately. What is clear is that cost-effective investments to improve growth and reduce mortality risks from fires, insects and disease can deliver financial benefits. Not making the correct timely investments can result in forest stands with much of the potential growth going into shrubs and trees with little or no commercial value. Investing in effective vegetation control is the key component of successful reforestation in California. In many cases, effective site preparation before the harvest and basic vegetation control during planting will be sufficient. In other cases such as the scenarios presented here, additional timely investments in brush control may be necessary to fully achieve the potential conifer growth of a site.

Conclusion

While the immediate costs per acre for any reforestation project are substantial, there will be many public and private benefits from successful reforestation projects. Documenting the necessary actions, their costs, and the eventual impact on future forest growth and revenues will be critical for convincing the landowners and other potential cost-share partners to invest in reforestation. The simple economics analysis tool illustrates how to assess the implications of various initial site preparation costs, cost-share payments, and assumptions about future revenues can have on the overall economics of a reforestation project. A clear and simple economic analysis can assist different forest land owners and managers who have different constraints and goals in planning and executing a successful reforestation project.

References

California Department of Forestry and Fire Protection. 2019. California Forest Improvement Program (https://www.fire.ca.gov/grants/california-forest-improvement-program/)

California Department of Tax and Fee Administration. 2019. Tax Guide for Timber Yield Tax. Timber Advisory Committee. (https://www.cdtfa.ca.gov/taxes-and-fees/timber-tax.htm - committee)

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

Greene JL, Siegel WC, Hoover WL, Koontz M. 2012. Forest landowners' guide to the Federal income tax. Agricultural Handbook No. 731 in Agriculture USDo, ed. Washington, D. C.

McDonald PM, Fiddler GO. 2010. Twenty-five years of managing vegetation in conifer plantations in northern and central California: results, application, principles, and challenges. PSW-GTR-231.

Pages 87 in PSW-GTR-231 GTR, ed. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

National Timber Tax Website. 2019. Tax Management for Timberland Owners. (www.timbertax.org)

Natural Resources Conservation Service. 2019. Environmental Quality Incentives Program. (https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/)

---. 2020. Environmental Quality Incentives Program. (https://www.nrcs.usda.gov/wps/portal/nrcs/main/ca/programs/financial/eqip/)

Oregon Department of Forestry. 2020 Timber Sales. (https://www.oregon.gov/ODF/Working/pages/TimberSales.aspx)

Stewart W, Ferranto S, Nakamura G, Getz C, Huntsinger L, Kelly M. 2012. Subdivide or Silviculture: Choices Facing Family Forest Owners in the Redwood Region. Pages 626 in Standiford RBW, Theodore J.; Piirto, Douglas D.; Stuart, John D, ed. Proceedings of coast redwood forests in a changing California: A symposium for scientists and managers. PSW-GTR-238, vol. Gen. Tech. Rep. PSW-GTR-238. . Santa Cruz, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, Albany, CA.

USDA. 2018. Reforestation Overview. (November 16, 2018; https://www.fs.fed.us/restoration/reforestation/overview.shtml)

Waks L, Kocher SD, Huntsinger L. 2019. Landowner perspectives on reforestation following a high-severity wildfire in California. Journal of Forestry

Wang L. 2019. Tax Tips for Forest Landowners for the 2018 Tax Year. US Forest Service Southern Region

Zhang J, Busse MD, Young DH, Fiddler GO, Sherlock JW, TenPas JD. 2017. Aboveground biomass responses to organic matter removal, soil compaction, and competing vegetation control on 20-year mixed conifer plantations in California. Forest Ecology and Management 401:341-353.

Chapter 3: Planning a Reforestation Project

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Introduction and Flow Chart

Successful reforestation in California is a complicated undertaking spread over multiple years. The planning process detailed in this chapter will help guide landowners, land managers, and reforestation practitioners through the myriad of steps necessary to meet their reforestation project goals. **It is important to realize that each step serves a specific purpose essential to the success of the project; failure at one can result in the reduced success or failure of the whole project even if all others are properly implemented.** Therefore, in all situations, the critical approach is to think through and plan out all the steps while being prepared to adjust the plan for unexpected complications, delays, or failures of the discrete steps. These basic steps are the same whether you are a small landowner, large landowner or a public agency, though slight modifications may be needed depending on project type and purpose. The three basic reforestation project types (and purposes) to be addressed in planning are: 1) post-harvest, 2) post-wildfire, and 3) rehabilitation / restoration.

Connecting the many reforestation activities that will occur over a number of years is also key to eventual success. To represent this process, the following Reforestation Flow Chart (Fig. 3.1) presents an overview of the necessary steps for each of the basic project types. In the sections that follow the chart, each of these steps is explained and references to the later chapters are offered where each practice is explained in more detail. The last section of this chapter offers "Schedule of Activities" spreadsheet examples of each of the three basic project types, with common details about the timing and interactions of the different steps. These examples are for general reference, as each project will need its own timeline based on the specific site where it is to be implemented.

Developing and Implementing a Plan: The Essential Steps in a Successful Reforestation Project

This chapter outlines the essential steps of reforestation planning and will guide readers through the complex process of forest establishment. Each section described a crucial step towards the ultimate goal of reforestation. References to other chapters in this manual are included where more detail is required.

REFORESTATION PLANNING FLOW CHART

Initiate a reforestation project
↓
Identify an experienced reforestation forester
↓
Define Project Type
↓
Define goals & Develop funding strategy
↓
Confirm availability of appropriate seed
↓
Perform a Site Assessment
↓
Define Specific Objectives
↓
Describe desired planting conditions and outcomes
↓
Develop prescription & schedule of activities
↓
Develop Budgets
↓
↓ ← **Reforestation Project Types** → ↓
↓

Restoration/rehabilitation	**Timber harvest/green sale**	**Post-wildfire**
↓	↓	↓
Forest Management/Restoration plan	Timber Harvest Plan	Exemption/Emergency Notice

↓
Identify Necessary Permits
↓
Obtain appropriate seed
↓
Order seedlings and identify cooler storage
↓
Contract for and conduct pre-harvest veg management spray
↓
Coordinate with Harvest operations
↓
Find Site Prep Contractors
↓
Vegetation Management: Mechanical/Manual/Burning/Chemical
↓
Request Timing of Seedling Packing and Delivery
↓
Find Planting Contractors
↓
Obtain seedling delivery
↓
Plant seedlings (or store seedlings for later planting)
↓
Planting Follow-up/Monitoring: (survival, density, veg competition, damage)
↓
Year 1 – Survival and establishment spray, if needed
Year 2-5: Release spray, if needed
↓
Treat for insects, disease & animal damage as needed
↓
Perform Pre-commercial thinning
↓
Perform Pruning and other fuel reduction treatments if needed
↓
DOCUMENT LESSONS LEARNED

Figure 3.1 Reforestation flowchart outlining the necessary steps for each of the basic project types.

Initiate a Reforestation Project

Reforestation projects in California are implemented by a diverse range of forest landowners. These ownerships cover everything from highly productive timberlands to non-commercial forests with mostly aesthetic and wildlife values and include very small private woodlands to very large public and private forests. For all landowners, the decision to initiate a reforestation project begins with the desire to accelerate positive changes in the forest that they own or manage. Often this decision is forced by timber harvest or by a wildfire. Despite the differences in motivation and objectives, the best management practices (BMP's) outlined in this chapter and described in detail within this book will lead to a successful reforestation project.

Identify an Experienced Reforestation Forester/ Silviculturist

The administrative and biological steps outlined in the flow chart above (Fig 3.1) must be executed in a timely manner. It is advantageous to seek the services of a forester with expertise in reforestation. Large private ownerships often have a professional reforestation staff or consultants under contract while small landowners may have an on-going relationship with a local Registered Professional Foresters (RPF). Within the private sector RPFs are licensed by the California State Board of Forestry and Fire Protection (BOF). Contact CAL FIRE for a list of RPFs in the project area (CFIP list will have better chance of finding foresters with reforestation experience): https://bof.fire.ca.gov/projects-and-programs/professional-foresters-registration/rpfcrm-rosters/. Federal agencies will have reforestation specialists within their organizations and sometimes may need to contract out for specialized skill sets.

Landowners should be aware that not all RPFs are experienced in reforestation due to differences in specialization and previous work experience. An RPF experienced in preparing and administering THPs or salvage logging contracts after a fire may not necessarily be the best choice for the subsequent reforestation project. The following considerations will help identify an RPF with expertise in reforestation:

- What reforestation projects have they done and how successful were these projects? Consider visiting some of the project sites.
- Ask for references from other landowners the RPF has worked with.
- Ask if they keep up with the most current reforestation practices? There are many opportunities for foresters to improve their reforestation skills. Attending reforestation conferences such as the Forest Vegetation Management Conference (FVMC) and the California Forest Pest Council (CFPC) Summer Weed Tour are excellent opportunities. These groups also help members network with other reforestation specialists.

- Does the forester have other licenses pertinent to reforestation? A forester with a Pest Control Advisor (PCA) license or a Qualified Applicators License (QAL)/Certificate (QAC) can make pest control recommendations or administer pesticide application contracts.
- If both harvest and reforestation activities are planned, consider hiring a firm or individual that is experienced with both.
- If different RPFs are chosen to manage the harvest and the reforestation effort, can they communicate with each other and coordinate activities as needed?

Define Project Type

Reforestation projects normally fall into three types; 1) Timber harvest: planting after a green timber harvest, 2) Wildfire: planting after a wildfire, 3) Rehabilitation or restoration: brush field conversion or reclaiming a site from exotic or invasive species. While each project type has its own characteristic needs and challenges, most projects need to follow the sequence of steps along the similar paths as shown in the Flow Chart. Different project types will have different timing constraints based on the status of the competing vegetation and the time needed to order the appropriate seedlings. Detailed schedule of activities for each of the three scenarios are described in the Schedule of Activities at the end of this chapter. More detailed information on different examples of project implementation is provided near the end of this chapter.

Define Goals & Develop a Funding Strategy

After the project type is determined, the goals of the landowner for the property need to be identified. A goal is a broad, general statement of intent that tends to describe a long-term vision. Examples include: produce income; enhance wildlife habitat; protect soil and water resources (OSU Extension, 2018). The US Forest Service's reforestation program has four major goals, such as "to improve the quality and yield of the timber resource" (USFS 2019). This goal-setting step is also essential to identify the relevant funding necessary to implement a project. Specific objectives to reach these goals should be developed after the site assessment phase when more details are known about the property.

Reforestation is an expensive long-term investment, as described in Chapter 2, "Investing in Reforestation". Acquiring the funding needed to complete the many steps of a multi-year project can be challenging, particularly for small landowners. Be aware that under-investing in necessary activities such as vegetation control and seedlings and planting will result in failure, or the need for additional, even more expensive, work to salvage the project. Identifying and pursuing the relevant financial grant assistance for reforestation activities from state and federal cost-share programs, when needed and available, is an important early first step. Grant approval can take anywhere from a couple months to more than a year after an application is received. It is important to plan for the reality that the timing of funding may not always coincide with climatic or biological windows that may dictate timing of each step.

Large landowners usually finance the project with a portion of the net income from the sale of forest products from the project acres and other private investment funds. The forester will need to document the plan and budget necessary for a successful reforestation project to get the necessary initial funding. The reforestation team will need to submit expense requests for inclusion in annual or multi-year budgets. For government agencies including the USDA Forest Service and the California Department of Forestry and Fire Protection (CAL FIRE), funding must be allocated from the general fund through spending bills from Congress or the State Legislature. A first step for an agency forester is to get the project listed (i.e., justified and internally approved) in the annual budget request for relevant programs (e.g., USFS's Vegetation and Watershed Management Program, federal Reforestation Trust Fund). It may be several years before the funds actually become available for use or disbursement for work already completed. A significant backlog in reforestation needs on federal lands is occurring as a result of the huge increase in acreage burned by wildfires, and administrative obstacles to salvage logging, and controlling competing vegetation.

Forest Management Plans

A written Forest Management Plan for a private property (or a unit of public agency land) can help guide reforestation planning in several ways. The geographic scale is usually the entire landowner's forest property, while the time scale provides a planning and expenditure horizon of at least 5 years with goals and objectives looking out over a much longer period. The plan will include much of the site assessment information relevant to long-term forest management that is also valuable for a successful reforestation project. A completed forest management plan will speed up the prescription process needed for reforestation planning.

A management plan can also facilitate reforestation funding, as described in more detail in Chapter 2. CAL FIRE requires a Forest Management Plan as a condition of receiving cost-share grants from the California Forest Improvement Program (CFIP), with 90% funding available to prepare the plan by an RPF for projects following a disaster such as a wildfire. Similarly, the Natural Resource Conservation Service (NRCS) asks that a conservation plan be done as a condition of its Environmental Quality Incentives Program (EQIP) grants, while the US Forest Service requires a plan for funding from its Forest Stewardship Program. The California Cooperative Forest Management Plan follows a common template to meet each of these agency requirements for grant agreements, as well as for grants from the American Tree Farm Association. In addition, CAL FIRE offers a Non-Industrial Timber Management Plan

(NTMP) option to promote long term management and planning on forest ownerships of 2,500 acres or less, with landowners agreeing to manage their forests through uneven-aged management and long-term sustained yield (Public Resources Code (PRC) §4593 et seq.). The NTMP can also be used to qualify for CFIP project funding.

Confirm Availability of Appropriate Seed

Without appropriate seed, a reforestation project cannot proceed. The importance of seed origin and quality to long-term reforestation success is well described in Chapter 5 – “Cone and Seed Handling”. Many years of research into California’s complex tree diversity and ecology are behind the division of California into the 85 separate and unique zones on the California Tree Seed Zones Map (depicted in Chapter 5, “Seeds”.) Within each zone, conifer seed collections are catalogued by 500-foot elevation bands and sub-zones less than 50 miles across. The potential that future climatic conditions may be considerably warmer for the mature trees has led to research into potential changes in guidelines for moving seed between seed zones and elevations.

Identify the necessary number of seeds, desired conifer species, seed zone and elevations for the project location before contacting conifer seed suppliers. Potential suppliers are the State Seed Bank at L.A. Moran Reforestation Center in Davis, private seed companies in California and neighboring states, and forest nurseries. The USDA Forest Service and some large landowners may also make seed available from their seed inventories if they have excess. Large landowners typically ask if the potential seed purchaser plans to follow all of the steps necessary for a successful reforestation project before selling their excess seed.

Finding out how much seed is potentially available for the project is a key step. An inadequate supply of seed might necessitate reducing the project size, planting fewer trees per acre (wider spacing), altering the species mix, or delaying the project until a suitable amount of seed can be obtained. Although determining the approximate quantity of seed needed and its availability is necessary prior to proceeding further, knowing exactly how much seed to order is determined later in the planning process (see the ‘Obtain Appropriate Seed’ section).

A landowner may choose to establish their own seed inventory to insure a supply of seed for future projects. This could be done by purchasing seed from one of the sources listed above or collecting and processing cones from their own or neighboring property with permission. How to collect cones when a good crop is present and process and store seed is also described in Chapter 5.

Perform a Site Assessment

The site assessment is the first step in the development of a project's specific objectives and schedule of activities. The site assessment begins with an in-office assessment of the relevant regional information on climate and fire risks and then drills down to the project site to identify a wide range of important characteristics of the project area so that all project planning is firmly based on the realities of the site. Most planning efforts use Geographic Information Systems (GIS) and spreadsheets to organize, analyze and map relevant site information and to identify unit boundaries and conditions. Other digital or manual methods may also be used. Site information may lead to the division of the project area into units with similar characteristics to which the same treatments will be applied. Unitization of the project area into more homogenous sub-units is particularly important when the project area is large. The on-site assessment provides detailed site-specific information plus ground-truthing of information originally derived from other sources. See also Chapter 4 – Site Assessment for a detailed explanation of this process and Chapter 12- Post-Wildfire Reforestation for an example of unitization.

Define Specific Objectives

A broad range of environmental and economic objectives may be possible for each previously defined goal. Making objectives quantifiable can be helpful to measure success and facilitate post-project monitoring. Some objectives are not as easily quantified as others (such as for aesthetics), but it is always valuable to have information relevant to defined metrics (such as desired trees per acre by species). Objectives can be short-term or long-term in timing and vision.

Examples of goals, specific objectives, and possible measurable criteria are in Table 3.1.

Table 3.1 Examples of Objectives for a Reforestation Project

Goal	**OBJECTIVE examples**	**Measures of Success examples**
Sustainable timber	Manage for a sustainable yield of commercial conifer timber trees. Manage for a broad mix of species for a sustainable yield of commercial conifer timber trees	-Meet post-harvest tree stocking needs per acre. -Meet total and per-species stocking needs per acre.
Forest health	Ensure seedling survival, vigor and growth by controlling competing vegetation. Maintain a tree density and species composition that will create a vigorous and healthy forest, including a diverse under-story.	-No competing vegetation within 5' of seedling for 1 to 2 years after planting and minimal competing vegetation for next 3 to 5 years. -Planted desired species to reach number of Trees per Acre (TPA) desired within X years.

		-Removal of undesired species on Y acres over X years. -Pre-commercial thin to desired species and number by age 10.
Fire protection	Maintain the condition of the property to minimize wildfire risk and allow for effective fire suppression and post-fire recovery.	-Create fuel breaks for fire suppression and maintain roads for access. -Brush and dead woody debris is at acceptable levels at specified plantation age(s)
Post-wildfire	Replant all productive forest soils in burned areas with appropriate species.	-Number of trees per acre per species alive and growing after 2 years.
Wildlife habitat	Retain oak species to provide acorns for wildlife. Retain pockets of shrubs and small wood debris for small mammal habitat. Manage non-conifer vegetation to stay within desired conifer/non-conifer mix.	-Site preparation effort retains xx oaks per acres, preferably large acorn producing oaks.
Natural diversity	Enhance native plant species by reducing invasive and non-native plant species that can have negative effects on plant diversity and abundance.	-Eliminate or control invasive plants to acceptable levels.
Aesthetics	Consider short and long-term effects on viewshed, especially near houses and high use recreational areas.	Develop a low density of large trees per acre in the viewshed.
Erosion Control	Provide for effective ground cover on eroding or potentially erodible sites.	No visible signs of (sheet, rills, ruts, gullies or mass movement), and no impacts to water quality.
Fuels management	Manage live and dead above ground biomass to keep fire behavior to manageable levels.	Keep live and dead above ground biomass to less than 10 tones per acre

Defining an objective with measurable targets is described further in the following examples.

Wildlife and Wildlife Habitat Objectives

Elements left on site such as oaks, snags, large woody debris and other elements that will be helpful to meet long-term objectives for wildlife habitat, recreation, aesthetics and water quality are also key objectives to track during any reforestation project. Treatments needed for successful reforestation will also affect the characteristics of the stand. Hardwoods such as oaks provide important food through acorns to many species of wildlife as well as valuable habitat elements for cover, denning, and nesting. Depending on the stage of the development of a stand, one could consider objectives related to habitat elements that are important for desired wildlife species such as:

- A certain basal area (BA) of stems or square feet of cross-sectional stem area per acre (e.g. approximately 2-10% of the total BA or number of stems in a stand).

- Snags are another important habitat element as the relatively rare large snags can provide important nesting and denning sites. Leaving so many per acre is a common way of describing objectives (e.g., 2 snags per acre over 20” in diameter.)
- Large woody debris provides habitat. Leaving large hollow logs that can be used for denning is very valuable (e.g., leave one large log greater than 30 inches in diameter, and at least 20 feet long per acre).
- Large diameter oaks can also provide important denning or nesting opportunities (e.g. leave one oak greater than 30 inches in diameter every 5 acres).
- Optimize habitat for game species at a forage-to-cover ratio of 60:40.
- Protect wildlife to the degree required while accommodating necessary forest management activities.
- Long-term objectives may be to have a mature mixed conifer or ponderosa pine stand with 10% oak cover. To achieve this objective, the forester will need to leave much less than 10% oak cover at planting to account for the growth of the hardwood canopies over time. A rapidly expanding oak cover can significantly diminish conifer growth if it exceeds the manager’s hardwood target.
- Brush and hardwoods are valuable wildlife habitat elements but compete with conifers for valuable resources and are ladder fuels for fire. Long-term objectives could include leaving a small specified percentage of the total area in brush and hardwoods for desired wildlife habitat areas.

Tree Density Objectives

The number of mature trees per acre (TPA) is the most widely used metric for assessing the success of a reforestation project after the initial decade. The initial number of seedlings planted will often exceed the projected number of mature trees to account for expected mortality and in some circumstances to promote more vertical tree form and to provide early revenue if there is a market for small diameter trees. California and other western states also have tree per acre requirements after green timber harvests on private lands. The requirements can be met with a combination of newly planted seedlings as well as residual trees. In 2019, the California Board of Forestry and Fire Protection reduced the initial TPA requirements from 300/150 TPA for high and lower sites to 200/100 TPA that are in line with the reforestation requirements of other western states. Planting higher densities of seedlings can result in more total biomass growth, but the trees will have smaller diameters and will take longer to reach the necessary diameter for commercial sale in regions without a strong market for small diameter trees. Within any area, it is also common to leave some pockets of non-commercial species, snags, leave trees, and clumps of understory vegetation as wildlife habitat elements. At planting, the number of TPA will vary depending on the species planted or whether it was a wildfire rehabilitation or green harvest where minimum stocking standards must be met on private lands or voluntary reforestation after wildfires or as part of a restoration effort. In terms of the long term financial and ecological value of a stand, it is the TPA following pre-commercial thinning (PCT) that matters. The decision rules for the pre commercial thin can include tree vigor, species, spacing, as well as wildlife habitat elements. Foresters can choose to aim for an initial planting density that is the desired final density, or plant more seedlings and then thin based on vigor, species, and spacing characteristics. As long as competing vegetation is not significant, the wider the tree spacing, the faster the trees will grow in diameter. At wider spacings, each tree has access to more water and other resources and is therefore more resistant to insect attack, disease, drought and climate change.

Fuels Objectives

Choices made during the implementation of a reforestation project can have major effects on the future fire risk on the site. Site preparation and vegetation management methods, retention of woody material for wildlife habitat, and tree density objectives should all be evaluated for fire risk potential. A fuel loading target of less than 10 tons per acre is often used to keep fire behavior at manageable levels. Photos of common fuel models for California can be viewed in the "Appendix B Fire and Fuels": https://gacc.nifc.gov/rmcc/predictive/Fire%20Behavior%20Fuel%20Model%20Descriptions.pdf. Additional information is available from the 'fuels and fire danger' page on the Rocky Mountain Area Coordinating Center web site at https://gacc.nifc.gov/rmcc/fuels_fire_danger.php.

Describe Desired Planting Conditions and Outcomes

Describing desired conditions applies to two timeframes: a) the physical and vegetative conditions at time of planting for successful survival and growth of the target seedlings; b) a series of post-planting conditions over time, leading to successful future outcomes. Long-term results could be from 10 to 70 years or more.

Determining the desired conditions at planting requires a thorough understanding of how planted conifers and competing vegetation will behave on a site. Important questions are:

- What will be the soil moisture and soil temperature conditions during establishment?
- What will be the air temperature, humidity, wind speed, and frost conditions during establishment?

- What is the shade tolerance of the preferred conifer species?
- What species are present in the under-story?
- How will potential competing vegetation respond after harvest, site prep or fire?
- How will the competing vegetation respond to treatment?
- What species of competing vegetation are present or are likely to germinate on site?

The regenerated stand will be a combination of species that have been planted, re-sprouted from root stock, and germinated from seed. Decisions will need to be made about which actions – or prescriptions - are necessary to achieve both the desired planting condition and the future forest condition. Conditions at planting to ensure seedling success vary for for different species. For example, Ponderosa pine is a shade intolerant species. Residual trees that shade pine should be removed. Pine dominated units are typically more than one acre in size. Douglas-fir has intermediate shade tolerance and young stems are sensitive to heat damage, so microclimate conditions are important. Large logs, small debris and an intact organic layer can provide favorable micro-climates for establishment. Douglas-fir and white fir are susceptible to frost mortality. Leaving some over-story trees by utilizing a shelterwood harvest, smaller group openings or leave trees for protection in frost-prone locations to reduce damage. The larger leave trees will be effective users of soil moisture and sunlight and will reduce the growth of the new seedlings, especially for the seedlings closest to the leave trees.

Develop Prescription and Schedule of Activities

The prescription process incorporates site assessment, objectives and desired conditions into a series of treatments designed to achieve the objectives. The timing of these treatments is described in "Schedules of Activities". Examples of schedules for several different project types which could be used as outlines for prescriptions are found at the end of this chapter. Depending on the landowner and the need for disclosure, prescriptions can be as brief as these schedules or quite lengthy documents detailing each step. Each activity on the schedule (e.g., plant seedlings) could also have its own detailed timeline as well as a separate budget.

Develop Budgets

The process of budgeting is facilitated by dividing the project area into smaller and more homogenous units - the unitization of the project. Providing accurate acreage for each unit in the mapping and spreadsheet data allows the forester to accurately estimate the cost of supplies, labor, timing, duration and other activities for each planning unit. Small landowners can use this information to justify funding when applying for grants. Large landowners and agencies can use the information for annual budgeting. If reforestation costs are being paid for with income from annual logging revenues, it is useful to know the timing of future costs so the land manager can retain income in the appropriate years. Landowners who do not budget well for post-planting release treatments, Pre-commercial Thinning (PCT), or other future treatments may not have the resources to invest in future activities that are critical to long term success. A spreadsheet covering at least 10 years of estimated costs from initial site preparation to PCT is helpful for identifying budget needs and avoiding serious funding constraints.

The primary purpose of budgeting is to identify the amount and timing of funding needed throughout the scope of the project. Skipping, or even delaying, a particular activity due to lack of funds at the appropriate time can jeopardize the success of the reforestation project, cause money that was spent on prior activities to be wasted, and require even higher future treatment costs. Budgeting can facilitate an assessment of priorities if funding is limited. In these cases, the spreadsheet developed for each unit during the site assessment (See Chapter 4) can be used to establish priorities among the units so that the available funding will be allocated to those units. Having a spreadsheet with all units from the mapping system also helps ensure that a unit will not be overlooked. When the budgeting process is completed, the spreadsheet can list by priority which units will be treated with the funding available. Similar lists, developed within an agency, can be used prepare proposals for bidding.

Implement Reforestation by Project Type

The following sections describe the many steps and timing involved to implement the three basic reforestation project types: restoration/rehabilitation, post-timber harvest (green sale), and post-wildfire. The largest differences will be in the timing of the activities to control competing vegetation, the ordering of seedlings, and acquiring the necessary permits. Once the seedlings are finally delivered to the site, the implementation of any project will follow a similar path. The timing or methods used in some steps may need to be modified, added to, or eliminated depending upon the specific project.

Identify Necessary Permits

Federal, state and local agencies require permits for several activities that may be part of reforestation projects. Permitting is an ever-changing process so it is advisable to check with appropriate agencies to determine the latest requirements. There are three general categories of permits which may be required:

Green Timber Harvesting and Salvage Harvesting Permits

Reforestation activities that are related to a green timber harvest on private land cannot begin until a Timber Harvest Plan (THP) that complies with the state Forest Practices Act and the California Environmental Quality Act (CEQA) is approved by the California Department of Forestry and Fire Protection (CAL FIRE). The preparation and approval of this permit can take from one to three years depending on the location and the issues involved. Reforestation needs should be determined in advance of the harvest so that once the plan is approved reforestation activities can be conducted at the appropriate times. Many of the surveys needed for the site assessment, including botanical, fish and wildlife, geological, and archeological, are required as part of the THP.

Post-wildfire reforestation activities on private and state lands are not usually delayed by the need for salvage harvest permits in California. Post-wildfire salvage logging operations may be conducted after filing an Emergency Notice or in some cases an Exemption Notice that may allow for logging to commence within 5 days after CAL FIRE accepts the notice for filing. Harvest operations conducted pursuant to Exemption and Emergency Notices must still comply with all of the operational requirements of the Forest Practice Rules. Exemptions have additional regulations and limitations compared to an Emergency Notice. An archeological records' check and other assessments may not be required for operations under an Exemption but the landowner and LTO are responsible to protect those sensitive resources. Prior to operations the RPF must still conduct an archaeological record check and survey along with other assessments to protect sensitive resources (e.g., botanical, fish and wildlife, and geological).

On federal lands, all timber sale operations need to comply with many federal laws such as the Multiple Use Act, National Environmental Policy Act (NEPA), Endangered Species Act (ESA), Clean Water Act, and the Clean Air Act. Projects going through the NEPA process can take two years or more to get approved and longer if appeals and litigation are filed. This uncertainty can complicate project planning and lead to operational delays.

Water Quality, Fish and Wildlife Permits

Most often these types of permits, or conditional waivers of permits, are related to timber harvest activities that can potentially affect the beneficial uses of water or threaten fish and wildlife. Examples include Regional Water Quality Control Board (RWQCB) Waivers of Waste Discharge Permit, California Dept. of Fish and Wildlife's (CDFW) 1600 streambed alteration permits, and CDFW surveys for spotted owls. Conditional waivers and 1600 permits can often be done within a month but can take longer. Surveys for the Northern Spotted Owl, protected under the state and federal Endangered Species Acts, can take up to two years. Salvage logging can still require these permits and surveys after a wildfire. Know what permits or waiver conditions are required and allow plenty of time to get them processed. The U.S. Fish and Wildlife Service, National Marine Fisheries Service and U.S. Army Corp of Engineers are some of the federal agencies that may also be involved, more often for timber harvest activities that could impact listed species or stream habitats. Some of these permits can take months or years to obtain.

Pesticide Application Permits

Pesticide application permits are issued and enforced by the local County Agricultural Commissioner (CAC) under authority of the California Dept. of Pesticide Regulation (DPR) and must be obtained before spray operations begin. To make pesticide applications for vegetation management in reforestation projects, an operator identification number (OIN) is required for the purchase and use of pesticides on the property. In addition to an operator identification number, a restricted materials permit is required for the application of pesticides (such as, specific herbicides and insecticides) that fall under the state restricted materials list (CDPR 2020).

An Operator Identification Number or Restricted Materials Permit for the application of certain herbicides or insecticides is required for reforestation projects (DPR 2018). The permit identifies the sites ("Site ID") where applications may be made and lists specific conditions to be followed during the applications. If the applicant for the permit is not the landowner, the applicant must have written authorization from the landowner designating them as the landowner representative and possess a Pest Control Advisor license (PCA) issued by DPR.

Unless they are working on their own property, applicators must also be licensed as a pest control business (PCB) and have a qualified applicator license (QAL) on staff in order to apply pesticides for hire and must annually register with the CAC in each county that work is performed. After application of any pesticide, the landowner or applicator is responsible for reporting the use in a specific format to the CAC. Use reporting can be done online or on approved forms available from the CAC. Written pest control recommendations may be required from a licensed PCA when the person conducting the reforestation program is not the landowner. More information on pesticide licensing, permits and reporting can be found in Chapter 8 – Vegetation Management.

Burn Permits and Plans

Burning as a site prep method may require a Smoke Management Plan (SMP) from your county or regional Air Pollution Control District (APCD) or Air Quality Management District (AQMD). The size of the project, quantity of emissions, and your proximity to smoke sensitive areas will determine if one is required. Some district may also require an Air Pollution Permit (APP). There can be fees associated with these permits. California's 35 local Air Pollution Control Districts are responsible for regional air quality planning, monitoring, and stationary source and facility permitting. The districts are the California Air Resource Board's (CARB) primary partners in efforts to comply with the Clean Air Act. Acquiring the approval of smoke management plans under the recent trend of a declining number of burn days has made burning within a reforestation project more difficult in recent years.

Private land owners may also need to obtain a Project Burn Permit (LE5) from their agency responsible for fire suppression (usually Cal Fire). The LE5 is required if you want to burn within fire season, which can last into December.

Obtain Appropriate Seed

A source for sufficient seed should have already been located. The project's prescription details should have estimates of the quantity of seedlings needed by seed zone, elevation and species. The best way to obtain the proper quantity of seed is to contact the seedling nursery that has been selected and have them determine how much seed they will need. They will need the seed lot identification, seeds per pound and germination rate. How much seed the nursery needs depends upon the seed quality and how efficiently the nursery uses the seed. (See Chapter 6-Seedlings.) If a reforestation forester knows that a particular seedlot is in short supply, informing the nursery of the situation can result in more efficient seed use.

Order Seedlings and Identify Cooler Storage

Seedlings should be ordered by the first week of December at the latest (See the "Ordering Seedlings "section in Chapter 6, "Seedlings" for more details). If ordered in November or December, then one-year seedlings will be available for planting the following fall (10-11 months later), the next winter (12-14 months later), or the second spring (14-18 months later). Timely seedling orders will allow the nursery to optimize seed treatment and sow dates and therefore provide the best quality seedlings. If you haven't grown the species or contracted with the nursery before, it's good to contact them in advance.

The project prescription will identify the species and seedling stock types (container size or bare-root age) that are best suited for the project and list the quantities of each that are needed. If seed for the project has already been obtained, then the nursery will need to know the quantity and quality of that seed to determine how much is needed to grow the requested number of seedlings. If seed has not already been obtained, the nursery can obtain the needed seed if some is available. The seedling purchaser will be responsible for the cost of the seed as well as the seedlings.

Chapter 6, "Seedlings," offers extensive information on selecting species, seedling stock types, and a forest nursery and more detail on how to order seedlings. Chapter 9, "Planting," has more detail on species and stock types commonly used in various regions of California. Packing windows for seedlings are getting shorter making cooler storage more critical. This is a particular problem for small landowners and consultants with relatively small and often periodic reforestation projects. Try to line up cooler storage when seedling orders are placed. Often, the nursery can provide or arrange for cold storage. If not, locate an alternative storage location. Do not wait until the seedlings are packed and ready for delivery and then try to find storage as nurseries usually have limited storage capacity. See Chapter 9, “Planting,” for more information on cooler storage.

Pre-harvest Vegetation Management Spray and Contractor Selection

Pre-harvest chemical site preparation before a green harvest, if done well, should substantially reduce the need for release treatments and reduce costs. These treatments to control competing woody and other vegetation occur before a site is logged so that the planted seedlings are not damaged. The treatments are particularly effective at controlling re-sprouting brush and hardwood species. Spraying should be done a minimum of three months prior to logging and depending on the species to be planted and the location, 1 to two years before planting. The need to spray before logging means that timber harvest or sale plans have to be completed well in advance. Having plans completed and approved two years before logging is tentatively scheduled will allow flexibility to still do the needed vegetation management treatment even if logging plans change. Road access can also be an issue. New road construction that provides access to the project area in the harvest area needs to be completed prior to treatment whenever possible to reduce labor costs and allow access into harvest units. Find a contractor equipped and experienced in pre-harvest chemical site preparation. This should occur at least six months if not a year prior to the planned application date to give contractors time to schedule the work, including securing a labor force. Permits for chemical use may also take time to obtain.

For more information, see Chapter 8, “Vegetation Management” and the examples at the end of this chapter.

Coordinated with Harvest Operations

Green timber harvest schedules often affect the timing of treatments needed for reforestation. Treatment plans may have to be adapted to account for changes in the timing of harvest. Harvest scheduling is often done to accommodate a mill’s processing capacity or the availability of a logging operator. Being involved with the scheduling process as much as possible will facilitate timeliness of reforestation treatments. Harvesting can take place any time of the year depending on the location and weather, but most logging is done from April through November. Some logging occurs on the east side of the Cascade or Sierra Nevada Range on snow or frozen ground from December through February. Logging can occur year-round on the Coast with well-rocked roads.

See “Identify Necessary Permits:Green Timber Harvesting and Salvage Harvesting Permits” for additional information.

Find Site Prep Contractors

All labor contracts need to be anticipated well in advance of when site preparation work needs to be done. Experienced crews and essential equipment operators are typically booked early. Getting a commitment from contractors several months prior to the project is wise. Seasonal availability varies by the type of site prep method. The summer season is very busy for equipment contractors, so the previous winter is a good time to locate and commit to a contractor to do mechanical site prep, for example. Spring can be the busy time for herbicide application contractors. Prescribed fire crews, who have a different skill than fire fighters, need to be available in the spring and fall burn windows. Plan ahead and be ready when your prescription window opens. Examples of three different Project Schedule are end of this chapter.

Site Preparation for Vegetation Management

Site preparation refers to any measure taken to prepare the site for regeneration of a forest stand and is considered by many practitioners to be the single most important step. Vegetation management is a primary controlling factor in successful reforestation. Chapter 7 describes how to determine the need for site prep and covers the three common methods: mechanical, manual, and burning. Chapter 8 focuses on the chemical (herbicide) methods of forest vegetation management used in the different steps of reforestation. Each method's advantages and disadvantages for various project sites should be evaluated, including their comparative cost and effectiveness. A combination of methods may also prove beneficial to seedling success.

Mechanical Site Preparation

Common reasons for mechanical site preparation include slash removal, vegetation control, reduction of soil compaction, and breaking up hydrophobic soils after a fire. Mechanical site preparation should be done in the summer or fall before planting to reduce the potential for undesirable vegetation re-establishing before planting. Where chemical pre-harvest site preparation has not occurred post-harvest chemical site preparation may be necessary. In this case, it is necessary to schedule chemical and mechanical treatments to allow for maximum efficacy while still accomplishing the objectives of any mechanical treatment.

See Chapter 7- "Site Preparation" for more information.

Manual Site Preparation

Manual labor can include grubbing, applying mulches, and hand piling. It is much more expensive per acres and tends to be used on sensitive sites such as steep slopes or urban-interface areas.

See Chapter 7- "Site Preparation" for more information.

Burning Site Preparation

The use of burning or prescribed fire as a site preparation tool is another option, although its use on private lands has declined significantly in recent years due to smoke management and liability issues. This method includes pile burning and broadcast burning.

See Chapter 7- "Site Preparation" for more information.

Vegetation Management-Chemical Site Preparation

Post-harvest foliar chemical site preparation may be necessary if pre-harvest chemical site preparation was not done or was ineffective. Some type of foliar treatment may be necessary during the summer prior to planting to control established woody brush and herbaceous vegetation. In some instances, depending on the species present, the unit(s) may need to sit fallow for a season to allow enough re-sprouting of woody vegetation to allow for eventual adequate chemical control when the plant is large enough to a absorb sufficient herbicide. This usually occurs where there are difficult to control species such as snowbrush, tanoak or golden chinquapin. The downside is that planting is delayed for an entire year.

Following pre- or post-harvest foliar site preparation treatments, scheduling of a residual herbicide application for herbaceous control needs to be planned in either the spring of or fall before planting depending on the elevation to control competitive grasses and forbs. Depending on the herbicide mix this may occur prior to or after planting.

See Chapter 8- "Forest Vegetation Management" for more information.

Request Timing of Seedling Packing and Delivery

The nursery should be contacted in the fall at least a month before packing begins to discuss the timing of seedling packing for a spring plant. Packing requirements should be discussed during the summer prior to planting if units are scheduled for a fall or winter plant. The approximate date(s) the seedlings are expected to be planted will affect their packing window and the type of cooler storage to use. Get your request in early and plan your cooler storage accordingly.

See Chapter 6- "Seedlings" and Chapter 9- "Planting" for more information.

Find Planting Contractors

Planting contractors can be very busy with existing commitments, so contact them as much as 6 to 12 months before their services are needed for your project. Government agencies that have lengthy contracting procedures, especially those with a complicated bidding process, may need even longer lead times to ensure that the planting contractors will be available for planting. See Chapter 9- "Planting "for more details.

Obtain Seedling Delivery

Seedlings packed for immediate planting, such as fall planting, will need to be picked up as soon as they are packed then stored properly, and planted within one to two weeks. Seedlings to be stored and planted later will be packed from November through January. Packed seedlings risk developing mold without proper storage. If storage at the nursery has not been arranged, seedlings need to be picked up immediately after they are packed and transported to cold storage. If the travel distance is long and the region is warm, transport in refrigerated truck or van may be warranted. The type of cold storage required near the planting site will depend on the length of time the seedlings will be in storage. See Chapter 9- “Planting” for more information.

Plant Seedlings (or store seedlings for later planting)

Planting is the culmination of the multi-step process leading up to it. Seedlings need to be properly handled with adequate transportation from the cooler storage to the field and then by the planters onto the site. Having an experienced planting crew, and good planting quality inspectors, will help ensure success. Doing all the other steps well will not guarantee success if the trees are not planted correctly.

See Chapter 9- “Planting” for more information about planting and storage.

Post-Planting Follow-up /Monitoring

It is essential to follow-up any planting project with periodic evaluations of survival, seedling density, vegetative competition and damage from insects, disease and animals. These monitoring activities will allow timely responses to post-planting changes on the site that can lead to poor performance or failure of the project.

See Chapter 9- “Planting” for more information.

Year 1-5 Survival and Release Sprays after Planting to Control Competing Vegetation

Release can occur any time after planting but usually occurs within one to five years after planting. Target weeds will vary by site and the appropriate treatment methods and/or chemicals will depend on the species, stage and condition of vegetation present. Depending on objectives, release may or may not be necessary. Release treatments done within one year after planting are usually done to assure survival rather than to improve growth rates. Treatments in years 2-5 are usually to control vegetation for enhanced growth and/or to reduce fuel loading for fire. If early post-planting monitoring indicates need for follow-up release spray, plan ahead to secure properly trained and equipped spray crews to complete the work. Securing a crew that is experienced in protecting seedlings from the spray is a must. See Chapter 8- “Forest Vegetation Management” for more details.

Monitor for Insect, Disease and Animal Damage and Treat as Needed

After planting, the site needs to be monitored for insect, disease and animal damage. Effective monitoring is based on knowledge of the agents that are in the area and what habitat they like. Insect problems are often controlled with good vegetation management, but this may be difficult on lower quality sites (i.e., low site index stands). Early identification will allow for timely treatment. Since the identification of insects and diseases may not be easy, assistance from State entomologists or pathologists and the Forest Health Protection (FHP) arm within the US Forest Service can be valuable.

For diseases, particularly root-based fungal rots, knowledge about pathogens in the area is helpful. For animal damage, knowledge of migration patterns or habitat issues in the case of small mammals can lead to successful preventative programs. If possible, schedule labor for any required treatments well in advance. Applications for insect infestations that occur over large areas are often aerial and lining up aerial contractors can be very difficult on short notice. Disease treatments are usually preventative and often occur at time of harvest. Animal damage is sporadic making scheduling of labor difficult. Some animal damage prevention if needed, can be done in conjunction with planting.

See Chapter 11- “Damage” for more information.

Perform Pre-Commercial Thinning (PCT)

The objective of pre-commercial thinning (PCT) is to establish a density of young trees that will grow into the desired sized trees over time. Treatments that involve pruning, branch removal, or other activities to reduce potential wildfire fuels that do not generate net revenue also promote the development of desired sized trees but are commonly referred to as ‘timber stand improvement’ (TSI) or fuels work. When the landowner has a dominant timber revenue objective, considerations might be: what size of tree is required for commercial viability, what are the price premiums for larger diameter trees, are there market reasons to favor certain species, and how will the treatments reduce potential wildfire losses? Ultimately, the goal of pre-commercial thinning is to prepare a forest stand to enhance commercially desirable qualities in the period between initial planting and when an initial economic return can be recovered.

The age at which precommercial thinning should be completed varies from site to site. Ideally, a thinning project should be implemented at the point where inter-tree competition begins to have a negative effect on individual tree growth. If the site also has competition from brush or hardwoods, the optimal time to do a PCT is when the conifers dominate the site but before growth per tree is constrained by inter-tree competition. Thinning before the time that the conifers dominate will in many cases result in a flush of growth from brush species that will negatively impact future tree growth. Plantations that started with fewer seedlings and a wider spacing will take a little longer for conifers to dominate the site and thinning should be delayed to around year 10. Delaying thinning past the optimum time not only slows growth rate of crop trees, but also increases the level of fuels from thinned trees. Thinning late also increases the cost of thinning projects as larger trees take longer to cut and pile.

Understanding these studies and integrating them into the decision to thin is important, but desired spacing ultimately boils down to a number. That number is the distance between trees the forester prescribes and the thinning contractor will be required to achieve. Foresters often tend to want to leave stands too dense and have a difficult time when watching thinning crews cut trees they have planted and cared for. It is important to follow through with this crucial step at the right time with the proper spacing for the long term health and productivity of the stand. The key decision For example, a common prescription for productive sites in Northern California starts with planting 200 to 260 seedlings per acre, followed by a precommercial thin to a 18'x18' spacing (129 tpa) at year 6-7 (later for lower quality sites or sites that were initially planted at a lower density) to set the stand up for the first commercial thin at year 25 -30 when the post-thinned stand will have 26' spacing with 65 tpa. The optimal time for thinning may be a year earlier for very productive sites and a year or two later for drier and less productive sites.

It's important to avoid conducting at PCT during the spring bark beetle flight of May through July in ponderosa pine stands as the beetles will be attracted to the freshly cut trees. As with all the other treatments, lining up labor ahead of time is critical. With thinning there is usually more planning flexibility but the earlier a plantation is thinned, the cheaper it is and the lower the fuel load.

Thinning plantations that are single species makes choosing which tree to cut and which to retain is a relatively simple task. The "best trees" will be retained at the prescribed spacing. "Best tree" could be the tallest or the one with no defect, but the most important consideration is thinning to the prescribed spacing. Thinning guidelines are more complicated in mixed species plantings where saplings need to be ranked in order of future value rather than simply by height.

See Chapter 10- "Pre-Commercial Treatments" for more information.

Perform Pruning and Other Fuel Reduction Treatments

If post-planting monitoring finds excessive accumulation of fuels in a plantation, then a fuel reduction treatment should be considered. Pruning of lower limbs is no longer a common practice to increase wood quality but it can reduce the probability of surface fires getting up into the branches and can facilitate fire suppression efforts in some circumstances.

See Chapter 10- "Pre-Commercial Treatments" for more information.

Document Lessons Learned

Learning lessons from the project should always be a continuous and not necessarily a final step: what worked well, what could have been done better, what failed – and why. Understanding why may not always be obvious, but documentation of the steps taken (or not taken) with text and pictures will contribute to a better understanding of the project's success – or lack thereof. Over time, the benefits of documenting lessons learned can substantially improve success rates.

Project Schedule of Activities: Some Examples

Three scheduling examples for different types of reforestation projects are provided in the following spreadsheet tables. Each schedule of activities provides a general example to facilitate the critical thinking necessary to develop and implement complicated biological, operational, and administrative processes. The left column in each example lists the series of activities that are necessary for successful execution of the project. These activities match the Flow Chart in Fig. 3-1. A description and where to find more information about these activities can be found in the relevant section of this chapter. The second column lists the chapter in this handbook where you will find very detailed information. The rest of the spreadsheet shows an example of when each activity might occur for this type of project. The numbers across the top show the years each activity may occur.

These schedules are examples only. Each project should have its own schedule of activities with a timeline developed for the specific needs of that site.

There are a lot of steps: think through your situation and come up with a schedule of activities (prescription/plan) that works for your particular situation.

Example 1: Post-Timber Harvest (Spring Planting) Schedule of Activities

This example in Table 3.2 is the most common form of reforestation because it applies to even-age forest management that is often practiced on large industrial ownerships. It can also apply to replanted group selection units that are considered un-even-age management under California regulations. Planting usually occurs during the spring as soon after harvest as possible if commercial conifer stocking levels are inadequate in the harvest area. However, many harvested sites can also be planted in the fall or winter if the conditions are right. See the "Planting" Chapter for details on planting seasons.

A post-harvest project has the benefit of a longer planning horizon because the planning of a harvest has to meet very detailed regulatory requirements that lead to a Timber Harvest Plan. The Schedule indicates this long lead time in the 3rd and 4th columns, with 1 to 3 "minus" years showing the time frame of certain pre-harvest activities prior to the reforestation phase. Although many steps are the same as for the other two reforestation types, post-harvest reforestation can benefit from pre-harvest biomass and spray treatments that are not possible with the other types of reforestation projects.

Example 2: Post-Wildfire Project Schedule of Activities

While the need for post-fire projects is becoming increasingly too common, reforestation success can be improved when planning begins immediately after the fire and the proper steps are taken (Zhang et al. 2008.) The planning and implementation timing of activities for salvage and reforestation after a wildfire, depicted in Table 3.3, is compressed considerably. Quick action with the salvage process will increase income to help offset reforestation costs. Wildfires tend to occur from June through November with later wildfires further compressing planning timelines.

The first activity for a successful and cost-effective response after a wildfire is usually a salvage harvest. The objectives are to salvage the dead wood and capture as much value as possible before the wood deteriorates and prepare the site so that is achieves its potential growth rate from residual and newly planted trees. This action usually is performed within one year, especially for smaller fire damaged areas. On private land, a Notice of Emergency Operations can be filed, and logging can start within 5 days of filing acceptance by CAL FIRE. The salvage operation still has to comply with all relevant Forest Practices Act requirements. Water Quality and Fish and Wildlife permits are still required. Archaeological record checks and surveys must be done prior to harvest operations. Large landowners have the advantage of having staff that can immediately get started and most know what they need to do, based on past experience with fires. However, large landowners that do not have manufacturing facilities, along with small landowners, need to take time for the extra step in marketing the salvage timber and executing contracts with mills and logging contractors. The decline in the number of sawmills in California over the past decades has made it more difficult and expensive to get logs to market. If other landowners also experienced fire damage, nearby mills may not have the capacity to process all the local fire killed trees. It is important to start the process of looking for potential log buyers and transporters as soon as possible after the fire loss.

Smaller landowners can be at a disadvantage for planning a salvage harvest after a severe wildfire, especially if they do not have an existing relationship with an experienced forester or have an existing Forest Management Plan. Many landowners lose not only their forestland but also their homes, so getting a place to live and dealing with insurance companies becomes the priority. Many are in shock and don’t know who to trust and want to wait to make a decision even though quick action will reduce reforestation costs and improve success. For those landowners who have the ability to deal with salvage and reforestation, time is of the essence. It is recommended to hire an experienced Registered Professional

Forester (RPF), preferably one with reforestation experience, as soon as possible. Foresters and loggers after a big fire are usually in short supply. Loggers can very quickly become committed to the larger projects of larger landowners. Ask foresters and loggers for their licenses and check with CAL FIRE about any problems with violations to help find trustworthy professional advice. If small landowners don't know the process or who to trust, they should call CAL FIRE and talk with the Forest Practices staff about salvage logging and the Forestry Assistance Specialist (FAS) about California Forest Improvement Funding (CFIP) for reforestation funding (see Ch. 2 – "Investing in Reforestation" for more information). Contacting these agency personnel can be difficult during and immediately after a fire since they may be working on that fire or another fire, as is often the case during fire season.

Salvage logging and reforestation funding applications need to be worked on concurrently. Applications for funding should ideally be filed by October 1 to have a chance at approval before December 1, so an order for seedlings can be placed. If the reforestation process is delayed for one year, the brush and grass can become well established, and then reforesting will be more expensive and success will be more difficult to achieve. Federal reforestation projects can take much longer as they require a NEPA process that can take 1-2 years, assuming no further delays from lawsuits and appeals. There is no emergency process for expediting post fire reforestation for the federal agencies. Once salvage logging is complete, the sequence of reforestation activities is very similar to all other type of projects.

Example 3: Rehabilitation Project - Brush Field Conversion Schedule

A rehabilitation project involves restoring conifer species to land previously forested but now dominated by other vegetation. The reforestation steps for this brush field conversion example vary from the other two types of projects primarily in the activity of site preparation (Table 3.4). Preventing the return of heavy brush after the site preparation with pre- and post- planting vegetation control is another key activity. Brush field conversions require less permitting related to harvestable trees than other reforestation project types. The permitting requirements are constantly changing, so landowners and foresters need to check prior to any project. Pesticide use permitting is required regardless of the project type. Brush field conversions are similar to a green timber harvest in terms of timely (rather than emergency) planning, but typically have much higher mechanical site preparation costs. A big obstacle with conversion projects, regardless of who owns the land, is funding. Small landowners may be able to get help with funding from federal and state cost-share programs.

Several approaches can be taken with brush field conversions. Tractor piling followed by burning of piles is very common. Where feasible the brush is typically sprayed with foliar herbicide(s) prior to piling in order to kill the root systems and facilitate piling. This "pre-piling" spray greatly reduces piling time and costs, reduces topsoil disturbance, facilitates burning of piles free of dirt and eliminates re-sprouting brush that otherwise would be very costly to control after planting. In either situation, the piling and burning activity is usually followed by a site prep herbicide before planting. Where herbicides are not used, then manual site prep is used as a release in conjunction with planting.

Table 3.2 Post-Timber Harvest (Spring Planting) Schedule of Activities Example

Biological Year	Chapter Detail	-2 to -3	-1												0												Growing Season 1												Growing Season 2												3	4	5	6	7	8	9	10-15
Steps			J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D								
Find or assign Reforestation Forester	3	x																																																								
General Objectives & Develop Funding Strategy	2 & 3	x																																																								
Find appropriate seed	5	X																																																								
Site Assessment	4	X																																																								
Specific Objectives & Prescription	3	X																																																								
Budgeting	3	x	x										x	x	x										x	x	x										x	x	x										x	x	x	x	x	x	x	x	x	x
Harvest Permit / NEPA or CEQA Compliance	3	X																																																								
Permits:WQ, CDFW, County Ag, others as needed	3	x	x	x								x	x	x	x	x									x	x	x										x	x	x										x	x	x	x	x	x	x	x	x	x
Obtain seed and order seedlings	6											x	x	x	x	x	x																																									
Identify Cooler Storage	6 & 8											x	x	x	x	x	x	x																																								
Contract for pre-harvest site prep spraying	3	x	x	x	x	x																																																				
Pre-harvest site prep spraying	9	x	x	x	x	x	x	x	x	x	x	x	x	x																																											
Harvest	7											x	x	x	x	x	x	x	x	x	x	x	x																																			
Find site prep contractor: mechanical	7													x	x	x	x	x																																								
Mechanical site prep	7																		x	x	x	x	x	x	x																																
Find post-harvest site prep spray contractors	3							x	x	x	x	x	x	x	x	x	x	x																																								
Post-harvest herbicide site prep	9																						x	x	x	x	x	x	x	x	x																											
Request Timing of Seedling Delivery	6 & 8											x	x	x							x	x	x	x																																	
Find Planting Contractors	3														x	x	x	x	x	x	x	x																																				
Obtain Seedling Delivery	6 & 8																							x	x	x	x	x																														
Plant seedlings (or store)	8																						x	x	x	x	x	x	x	x	x	x																										
Follow-up /Monitoring	3 & 10																						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Find contractor for spraying	3										x	x	x	x	x	x	x	x	x	x					x	x	x	x	x								x	x	x	x	x								x	x	x	x	x					
Year 1-5 Survival & Release spray to control competing veg, as needed	9																		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					
Find contractors for damage (Insect, Disease, Animals) control	3														x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Treat for Insect, Disease or Animal Damage as needed	10																							x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Find contractor for PCT	3																																																				x	x	x	x	x	
Pre-Commercial Thin (PCT)	11																																																					x	x	x	x	
Find contractor for Pruning	3																																																									x
Pruning / Fuel mgt.	3																																																									x

Table 3.3 Post-Wildfire Project Schedule of Activities Example

Biological Year	Chapter Detail	Fire												0												Growing Season 1												Growing Season 2												3	4	5	6	7	8	9	10-15
Steps		J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D								
Find or assign Reforestation Forester	3						x	x	x	x	x	x	x																																												
Find Contractors: Logging and Mill	3						x	x	x	x	x	x	x																																												
Define General Objectives & Funding Strategy	2 & 3						x	x	x	x	x	x	x																																												
Find appropriate seed	5							x	x	x	x	x	x																																												
Site Assessment	4						x	x	x	x	x	x	x																																												
Specific objectives, desired planting conditions & outcome, prescription, schedule	3							x	x	x	x	x	x	x																																											
Budgeting	3						x	x	x	x	x	x	x	x										x	x	x										x	x	x										x	x	x	x	x	x	x	x	x	x
Small Landowners apply for reforestation funding	2								x	x	x	x	x	x	x				x	x												x	x											x	x					x	x	x	x	x	x	x	x
Permitting: Salvage Harvest / NEPA or CEQA Compliance	3						x	x	x	x	x	x	x	x																																											
Permits: WQ, CDFW, County Ag, Arch. Survey	3							x	x	x	x	x	x	x										x	x	x										x	x	x										x	x	x	x	x	x	x	x	x	x
Obtain seed and order seedlings	6										x	x	x																																												
Line up Cooler Storage for Seedlings	6 & 8												x	x	x	x	x	x	x	x	x	x	x																																		
Find site prep contractors							x	x	x	x	x	x	x	x	x																																										
Pre-harvest veg mgt spray							x	x	x	x	x	x	x																																												
Harvest - Salvage	7							x	x	x	x	x	x	x	x	x	x	x	x																																						
Post-Harvest mechanical site prep	7																x	x	x	x	x	x	x																																		
Find Contractors for planting, spraying, PCT, etc.	3									x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Post-Harvest chemical site prep	9																					x	x	x	x	x	x	x	x	x	a	a	a	a																							
Obtain seedling delivery	6 & 8																							x	x	x	x																														
Plant seedlings (or store)	8																					x	x	x	x	x	x	x	x	x																											
Follow-up /Monitoring	3 & 10																					x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Year 1-5 Survival & Release spray to control competing veg., as needed	9																													x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					
Treat for Insect, Disease or Animal Damage as needed	10																						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Pre-Commercial Thin (PCT)	11																																																				x	x	x	x	x
Pruning / Fuel mgt.	3																																																								x

a=alternative application due to delay in planting

Table 3.4 Rehabilitation Project – Brush Field Conversion Schedule of Activities Example

Biological Year	Chapter Detail	-2	-1												0												Growing Season 1												Growing Season 2												3	4	5	6	7	8	9	10-15
Steps			J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D								
Find or assign Reforestation Forester	3	x																																																								
General Objectives & Develop Funding Strategy	2 & 3	x																																																								
Find appropriate seed	5	X																																																								
Site Assessment	4				x	x	x	x	x	x	x																																														
Specific Objectives, Prescription, Scheduling	3				x	x	x	x	x	x	x																																														
Budgeting	3	x	x	x																					x	x	x										x	x	x										x	x	x	x	x	x	x	x	x	x
Permitting - NEPA or CEQA compliance	3	x	x	x																					x	x	x										x	x	x										x	x	x	x	x	x	x	x	x	x
Permits:County Ag, Co. Burn; WQ, CDFW if needed	3	x	x	x																					x	x	x										x	x	x										x	x	x	x	x	x	x	x	x	x
Obtain seed, Order seedlings at nursery	6											x	x	x	x	x	x	x																																							
Identify cooler storage for seedlings	6 & 8												x	x	x	x	x	x	x	x	x	x	x	x																																		
Find Site Prep Contractors: Equipment and/or Burning/Spraying/Grubbing	3								x	x	x	x	x	x	x	x	x																																								
Pre-Pile Spray (if feasible)	3 & 9	x							x	x	x	x	x																																												
Brush Conversion: mechanical piling, burning	6																				x	x	x	x																																	
Find Contractors for planting, spraying, PCT, etc.	3								x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Request Timing of Seedling Delivery	6 & 8																				x	x	x	x																																	
Post-conversion herbicide or manual site prep	9																				x	x	x	x	x	x	x	x	x	x	x																										
Obtain delivery of seedlings	6 & 8																								x	x	x	x																													
Plant seedlings (or store)	8																						x	x	x	x	x	x	x	x	x	x																									
Follow-up /Monitoring	3 & 10																						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Year 1-5 Release to Control competing veg. grass & herbaceous, brush or hardwoods, as needed	9																														x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					
Treat for Insect, Disease or Animal Damage as needed	10																						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Pre-Commercial Thin (PCT)	11																																																					x	x	x	x	x
Pruning / fuel mgt.	3																																																									x

Summary

Positive progress with reforestation over the past several decades has led to many changes in the details of planning a project. However, certain common-sense planning recommendations and principles from a 1992 reforestation guide from Oregon (Hobbs et al.1992) still ring true for California today:

- *The region's environment and its well-adapted non-conifer vegetation interact to create often-hostile conditions for survival and growth of seedlings. Such conditions require careful and timely execution of well-thought out plans for reforestation.*
- *In order to succeed, managers must work to identify long-term objectives.*
- *Regardless of management objectives, sustainability of forest productivity must be a primary concern, with a major component of sustainability being reforestation after natural disturbance or harvest. An understanding of (1) ecological principles, (2) management practices, and (3) analysis capabilities pertinent to the reforestation process is relevant to managing lands for all of the listed purposes.*
- *Managers must make monitoring of reforestation efforts by technically competent people a high priority.*
- *Actions must be biologically sound, make economic sense, be socially acceptable and be operationally feasible.*

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References

CAL FIRE. 2020. Forest Practice. https://www.fire.ca.gov/programs/resource-management/forest-practice/

California Department. of Pesticide Regulation (CDPR). 2019. What you need to know about: The permit process for restricted pesticides. Sacramento. 3 p. https://www.cdpr.ca.gov/docs/dept/factshts/permitting.pdf

California Department. of Pesticide Regulation (CDPR). 2020. Restricted Materials Use Requirements. (https://www.cdpr.ca.gov/docs/enforce/permitting.htm)

DiTomaso, Joseph, et al. 1997. Post-fire herbicide sprays enhance native plant diversity. California Agriculture 51 (1).

Dreistadt, S.H. (ed.) 2013. Forest and Right-Of-Way Pest Control. 2nd edition. U.C. Statewide Integrated Pest Management Program. UCANR publication 3336. Oakland, CA.

Hobbs, S.D., Tesch, S.D., and P.W. Owston. 1992. Reforestation Practices in Southwest Oregon and Northern California. Forest Research Laboratory, Oregon State University. Corvallis OR. 465 p.

McDonald, Phillip M., and Fiddler, Gary O., 2010. Twenty-Five Years of Managing Vegetation in Conifer Plantations in Northern and Central California: Results, Applications, Principles, and Challenges. USDA Forest Service PSW-GTR-231.

Oregon State University (OSU). 2019. How to Manage Your Forest. http://extensionweb.forestry.oregonstate.edu/programs/how-manage-your-forest

Payn, T., et.al, 2015. Changes in planted forests and future global implications. Forest Ecology and Management 352 (2015) 57-67.

Powers, R., 2004. Management techniques used in intensively managed plantations of the Pacific Northwest and their environmental consequences – an overview. Intensive Plantation Forestry in the Pacific Northwest Symposium, January 2004.

Ritchie, M. W., and Knapp E. E., 2014. Establishment of a Long-Term Fire Salvage Study in an Interior Ponderosa Pine Forest. Journal of Forestry 112(5) 395-400.

Rose, R. and D. Haase, 2006. Guide to Reforestation in Oregon. Oregon State University, Corvallis OR. 48 p.

Schubert, G.H. and R.S. Adams, 1971. Reforestation Practices for Conifers in California. California Div. of Forestry, Sacramento.

U.S. Forest Service. 2019. Reforestation Overview. www.fs.fed.us/restoration/reforestation/overview.shtml

Weatherspoon, Phillip C. 1995. An Assessment of Factors Associated with Damage to Tree Crowns from the 1987 Wildfires in Northern California. Forest Science 41 (3): 430-451.

Zhang, J., J. Webster, R.F. Powers, and J. Mills. 2008. Reforestation after the Fountain fire in northern California: An untold success story. Journal of Forestry 106:425– 430.

Chapter 4:
Site Assessment

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Introduction

A site assessment is an essential step to developing a plan for successful reforestation. Before conducting the on-site assessment, reforestation practitioners should take the time in the office to collect relevant data from local and regional databases and prepare maps utilizing geographic information systems. This office or pre-field compilation, organization, and preliminary analysis of information is an efficient step that will benefit an immediate project as well as all future projects. As more detailed historic, current, and future projection information becomes available, it is important for practitioners responsible for more than a single project to keep the 'pre-field' compilation up-to-date with new resources as they become available. The on-site, or field assessment is key for verifying and adjusting the data from the pre-field compilation, and capturing key operational and logistical characteristics that also will contribute to successfully implementing the plan. Examples of practical on-site assessment forms are the Site Assessment Template and Unit Planning Information Sheet in the appendix. A completed Reforestation Site Assessment and Project Plan example is also in the appendix.

While on the site, important elements of the prescription should be considered such as appropriate tree species, planting density, competing vegetation, soil conditions and any limitations on planting access. The site visit is also an opportunity to ground-truth data acquired during the office research phase of the assessment. If the reforestation project is part of a green harvest, then an on-site assessment will be needed both before and after the harvest. The pre-harvest visit will assess the existing stand and the need for pre-harvest site preparation treatments. It can also assess the possibility of using the logging to help with site preparation and allow the forester to be involved in planning the harvest. The post-harvest visit will assess the conditions on the site after all logging activities have ended, allowing for an adjustment to the plan if needed.

Linking Pre-field and On-site Data for Effective Decision Making

The following table summarizes the assessment topics and which types of relevant information will need to be collected in the pre-field and on-site components of a site assessment. In many cases, the on-site work can be used as a verification that the data collected in the office assessment is valid. In some cases, especially those requiring identification of vegetation, the on-site assessments will be critical.

Table 4.1 Site assessment categories to be collected in the office or the field for each unit

Assessment Category	Topic	Pre-field	On-site
Location	Ownership	X	
	Legal description	X	
	Property lines & corners	X	X

Assessment Category	Topic	Pre-field	On-site
	Acreage	X	X
	Neighboring properties	X	X
	Road access	X	X
	Easements and utilities	X	X
	Seed Zone	X	
Topography	Elevation	X	
	Slope	X	X
Climate	Precipitation	X	
	Temperature/humidity	X	
	Wind	X	
	Frost pockets	X	X
Soils	Soil type/texture	X	X
	Avail. Water Storage (AWS)	X	X
	Organic matter content	X	X
	Soil stability & erosion	X	X
	Soil maps & data	X	X
Vegetation	Site class	X	X
	Natural Regeneration		X
	Size and age class		X
	Vegetation species & cover	X	X
	Treatment Needs		X
	Conifers prior to harvest/fire		X
	Harvest history	X	X
	Fuel Loading		X
	Wildlife habitat elements		X
	Conifer Seed Zone	X	
Silviculture	Logging method	X	X
	Silvicultural method	X	X
	Site prep needs		X
	Planting needs		X
Sensitive Sites and Species	Water quality	X	X
	Aquatic species	X	X
	Endangered species	X	X
	Archeological sites	X	X
Pests, Insect, Disease	Animal damage		X
	Insects and disease		X
Fire Risk	Surrounding stands	X	X
	Residual crown fuels		X
	Ladder tree and shrub fuels		X
	Snag and down wood fuels		X
	Predicted plantation fire risk		X

Making and Utilizing Maps During the Pre-field Assessment

Compiling and utilizing existing data to make site-specific maps is a critical element for reforestation planning. Virtually all activities will utilize the maps. Reforestation foresters must be aware of what other informational maps are available that will aid in reforestation planning and create the necessary maps. Unless the project is very small, utilizing computer based geographic information systems (GIS) will be an essential step for both operational and regulatory activities. Table 4.2 provides an overview of the many topics that will be useful for reforestation and whether the data can be collected at the office, requires on-site visits, or both. In most cases, the utilization of information collected from sources available at the office will be more cost effective, especially for large operations. On-site evaluation is often mainly a verification that the previously mapped data is correct but the field assessment should also identify specific locations where different actions will need to be taken.

Using Geographic Information Systems (GIS) in Reforestation Assessment, Planning and Implementation

The most critical part of organizing data is determining what data are needed and how they will be used. A valuable tool for organizing and presenting all the data available is a geographic information system (GIS) software package. The development and widespread use of various GIS software packages, especially when used in conjunction with spreadsheets, has greatly improved the forester's ability to organize and track information. Spreadsheet data can easily be exported to or imported from GIS software for further advancing analyze that can be useful for making management decisions.

Mapping of Operational Units with Similar Characteristics for Seedling Survival

For effective reforestation projects, the primary goal is to define units that have similar physical characteristics and can be treated with the same package of treatments A GIS allows for easy and accurate mapping of the planning units based on the data sources used, as well as tracking during implementation and follow-up. Not all data layers need to be utilized in reforestation projects, as some of the layers may be more general and more relevant for larger scale reforestation programs or longer term projections. Planning and operational units, usually just called 'units', are sub-areas within the project boundaries with similar biological and operational characteristics. These characteristics include soils, aspect, slope, water availability and site quality. Draft units can be delineated prior to field assessment and then verified in the field or created during the site visit by drawing lines or by laying the unit out and taking GPS points. Once the units are created and are given a unique identifier, relevant site assessment information can be tracked by unit, and specific operational or landscape level prescriptions can be applied to each unit.

GIS does not just create pretty maps but more importantly serves as a data management tool. Once the data are created either through direct input or GIS calculation, it can then be easily exported to a spreadsheet for analysis and organization. Units can be sorted by size, soil type, site class, water holding capacity, slope, year of planting, or any other factor for which data is available. If data are added to a spreadsheet, it can be merged back into the GIS system provided it is tied to a unique identifier. The ability to link GIS systems with spreadsheet data has increased the organizational abilities and efficiencies of planners and implementers significantly over the last two or three decades.

Key Regional Datasets for Baseline Maps

Before collecting and integrating on-site level data into a GIS, it is valuable to integrate some of the key regional key site factors (Lavender et al. 1990, Spittlehouse and Stathers 1990, Stathers et al. 1990) that have been well documented to affect seedling survival and growth. The five broad categories of necessary information are:

- locational attributes
- climate
- soil
- vegetation
- fire risk

Some of the themes can be primarily addressed with regional data available from published maps and databases, but others will require on-site assessments and verifications. There are many sources for regional data that are constantly improving. It is important to realize that regional datasets and spatial coverages have often created by interpolating between a relatively small number of field plots and therefore may not be accurate at the microsite scale that often determines seedling survival. Successful reforestation must use both the regional information that is now available for most forest regions with the local and microsite information that can only be collected with detailed site visits.

Pre-Field Site Assessment

Office research will supply important information about the site from local and regional databases and a variety of other relevant documents. The maps and data acquired during map development are essential to the next steps in site assessment process. Data available online and from other sources include information on soils, vegetation types, botanical surveys, endangered species, archeological sites, logging history, and climate. This information is useful to field personnel in preparation for conducting onsite-specific analysis and is important when planning a reforestation project.

Making a Site Map

A comprehensive base map is the foundation of a site assessment. It is needed to organize information and to divide the site into units with similar treatments. The elements (layers) of a useful map include:

a) Contour lines for information on elevation, slope, aspect and topography. Traditional survey data is available from US Geological Survey (USGS) sources and other sites that often combine the basic data with other information. More advanced sources of detailed elevation data including LiDAR, radar, and advanced photogrammetry are constantly being improved and are increasingly used in forest management in the United States, Canada and Europe.

b) Roads to determine access. Data on roads is available from many sources:

- Counties and state agencies often have GIS layers that are up to date and downloadable;
- Most large companies and agencies have their own databases;
- Aerial photography and imagery can be used to determine road locations.

The locations, condition, and accessibility of all office mapped roads relevant to the project should be confirmed during site visit(s).

c) Water features including springs, streams, lakes and watersheds. Domestic water sources (ditches, water intakes, wells, etc.) need to be mapped to give adequate protection from silvicultural treatments and to minimize liability. Identifying specific water drafting source(s) is also important for spray operations and road dust abatement operations, if needed. In addition to state agency resources, the National Hydrography Datatset (NHD) managed by the US Geological Survey is an excellent source of accurate data on streams, lakes, and watershed boundaries (United States Geological Survey 2019b)

d) Property lines, property corners, utility and access easements, and parcel data for determining ownership and ownership patterns. These may affect road right-of-ways, access to the property and, depending on neighbor concerns, which treatments can be used.

e) Infrastructure, such as buildings, powerlines, waterlines, wells, water intakes and gates, are some of the structures that may affect management decisions and mitigation measures.

f) National Agriculture Imagery Program (NAIP) with digital ortho-photography gives aerial images of vegetation patterns that are useful for vegetation typing and other data development (United States Department of Agriculture Farm Services Agency 2019). GIS contours can be overlaid on the imagery to provide a contour map and vegetation typing all in one.

Locational Attributes

Ownership information for both the subject property and neighboring properties can be obtained from the county assessor's offices, past Timber Harvest Plans (THPs), or other online sources. This information, including maps, can provide the legal description, property lines and corners, neighboring property owners and identify access and utility easements across the property. All legal owners of the subject property must be identified prior to any activity. Acquiring adjacent ownership information is important to ensure that access permission is obtained before a project is undertaken. Rough acreages for the project may be obtained from initial mapping efforts. As mentioned above, seed zone maps can be obtained from Cal Fire's FRAP website for the project area to identify the appropriate conifer seedlot(s) to use for growing conifer seedlings in the project area.

Coverages for locational attributes such as elevation, latitude and longitude, slope, aspect are included as base maps in most GIS systems. Additional data can be downloaded from the USGS (United States Geological Survey 2019a) and other entities. More detailed products using technologies such as new satellites, LiDAR, radar, and advanced photogrammetry are continually being developed. The more advanced systems provide data at a much finer scale that may provide valuable microclimate data relevant at the individual planted seedling level. The advantages of using the more detailed information need to be weighed against the higher costs and limited track record on their long term efficacy in creating the desired stand of mature trees over the next few decades.

Topography

Basic topographical information including elevation, slope and aspect can be gathered from topographic base maps that are available in digital form. Elevation ranges must be identified for each management unit. This data, along with vegetation, soil, logistical and other operational information can be used to divide the project into units. These units can be sorted and organized by similar prescriptions, schedule of activities and cost. Elevation is a critical factor for determining conifer seed requirements, conifer species, planting window, access issues, vegetation control and spray timings.

Slope influences water and air drainage and soil stability. Flats areas may be frost pockets that require planting frost tolerant conifer species. Slope also influences what management tools are available due to operability constraints on mechanical equipment. Slope can also significantly influence the viability and cost of mechanical or manual treatments.

Aspect has a strong influence on micro-site and vegetation complex, and therefore has a strong influence on vegetation management prescriptions. Aspect is often used to define units of a project due to its strong influence on many management activities. North facing slopes receive less solar radiation and are therefore colder and have less evaporation. South facing slopes are warmer and can often be planted earlier but also will experience low soil moisture availability earlier. Aspect will affect the choice of conifer species to plant and the timing of planting. Sites with different aspects can have very different soil surface temperatures and retain snow for significantly different periods of time. North and others (2019) suggest that topography, slope, and aspects serve as an appropriate ecological foundation for reforestation decision making that may drive changes in reforestation tactics.

Climate Data

Climate will dictate many decisions in formulating a reforestation plan. The species planted, stock size, planting season and timing of vegetation management treatments are all influenced by climate. Most climate information can be obtained before conducting an on-site field assessment. The most important climate factor for reforestation in Mediterranean climates is precipitation. Since available soil water is the greatest limiting factor on seedling survival, the initial precipitation sets the limit on how much water will eventually be available for potential storage in the soil profile and available for seedlings growth. In general, reforestation efforts are more successful on sites with high precipitation and more challenging where water is limited. The timing and type of precipitation will influence reforestation plans. Areas where precipitation occurs mainly as rain throughout the winter are usually suited to planting between winter and early spring with spring applications of residual herbicides. In contrast, high elevation sites where precipitation mainly occurs as snow and can impede access may be more conducive to fall planting or fall residual herbicide applications or planting from early spring to late spring..

Extreme temperature and wind can negatively affect conifer seedlings growth and survival (Kolb and Robberecht 1996). High temperatures can cause sunscald that girdles the cambium of tree seedlings, while high winds can lead to desiccation and abrasion issues. Climate data may help forecast these conditions so that the forester can potentially mitigate the issues through stock type, natural or man-made sunshades, planting season or mechanical site preparation method. Topographic maps can be useful for identifying potential frost pockets that may be verified in the field.

Before beginning the on-site assessment and creation of operational maps, baseline maps from available regional data sets should be compiled, especially for large projects. If the landowner does not have locally relevant climate records, current and historical climate data relevant for reforestation in California can be downloaded from sites such as the Desert Research Institute, PRISM, and Cal-Adapt (Desert Research Institute 2019, PRISM Climate Group 2019, UC Berkeley's Geospatial Innovation Facility (GIF) Cal-Adapt). Those entities have developed wall to wall map layers based on advanced modeling of the data from many weather stations on temperature, precipitation, wind, solar radiation, fire weather and vapor pressure deficits. Having better information beforehand on these factors can have significant value on determining what steps should be taken to guarantee high seedling survival. The species we plant are long-lived species (100 years plus) and climate is predicted to change during this period. Tools like Cal-Adapt may help foresters bet-hedge against future climate change by adjusting species, seed zones by incorporating this analysis into their pre-field assessment. This is beyond seedling survival but more apropos to tree persistence. For example, the historic temperature and precipitation data can provide information on the probability of future drought or high temperature conditions that may warrant even greater attention to controlling water use by competing vegetation (Balandier et al. 2005, Zhang Jianwei et al. 2013) the potential utility of seedling shade devices, and the choice of more drought tolerant seedlings (Young et al. 2019).

Soils Data

Soil is the very foundation of the forest ecosystem and critical to its sustainability. Knowing the soil type is helpful in determining whether the site can support a conifer forest, the likely productivity of the site and potential limiting factors. The most relevant soils data sets are all based on the Natural Resources Conservation Service (NRCS) Web Soil Survey data and are accessible through a number of applications that present the data in a variety of easy to use formats for both desktop and mobile devices. Characteristics of soil types that are useful in developing plans are: soil texture (percent sand/silt/clay), depth to bedrock, rock content and available water storage (AWS). Other relevant factors include organic matter content, nutrient availability and mass movement potential. For example, in conjunction with climate data, and aspect, soil texture and AWS can influence which species to plant. Depth to bedrock or hardpan, nutrient availability and AWS combine with climate and aspect to influence productivity. Rock content and compaction can affect the choice of planting tool, seedling stock type and cost (See “Planting” Chapter). Organic matter content can affect the choice and rate of pre-emergent herbicides used for vegetation control (See “Vegetation Management” Chapter) (Neary et al. 1983) . Identifying unstable soils is necessary for developing operational constraints and mitigation measures. Coarser soils with low organic matter are more susceptible to erosion and may need wider equipment and spray buffers. Sandy soils have lower water holding capacities but are less susceptible to compaction during harvest and mechanical site preparation. Soil color can influence heat reflectance and soil temperatures.

Soils data is readily available for most forested areas of California from the Natural Resources Conservation Service (NRCS) Web Soil Survey and the California Soil Resource Laboratories (CSRL) Soil Web application hosted by the University of California Davis. Since the original data is mapped at a 1:20,000 scale, users should realize that the accuracy of the information may not be accurate for small mapped units. Reports also include vegetation data on conifer, weed and brush species associated with each soil type. Links for the two sites can be found at http://websoilsurvey.sc.egov.usda.gov/app/websoilsurvey.aspx NRCS Web Soil Survey and https://casoilresource.lawr.ucdavis.edu/ CSRL Soil Survey and SoilWeb Apps.

An example of how Soil Web Survey data is used for reforestation decisions can illustrate its value. Figure 4.1 shows a soil type map of an area within the reforestation after the 1992 Fountain Fire (Zhang Jianwei, Jeff Webster, Robert F. Powers, John Mills 2008). Using the NRCS Web Soil Survey site, a specific 'Area of Interest' was chosen to provide insights into the relative reforestation success in the area. After the fire, Douglas-fir conifer seedling survival planted in the mid 1990s on Cohasset soils was better than on Windy-McCarthy. Table 4.1 shows a significant difference in available water storage (AWS), with Windy-McCarthy soils having a much lower AWS than Cohasset. A lower AWS indicates less total water availability in the soil profile, greater competition for water by all plants, and hence a greater need for vegetation management to ensure survival and growth of the planted seedlings. A low AWS is also an indication of the potential benefits of planting conifer species such as ponderosa pine that are more adapted to harsher sites, rather than species such as true fir or Douglas-fir that need more water.

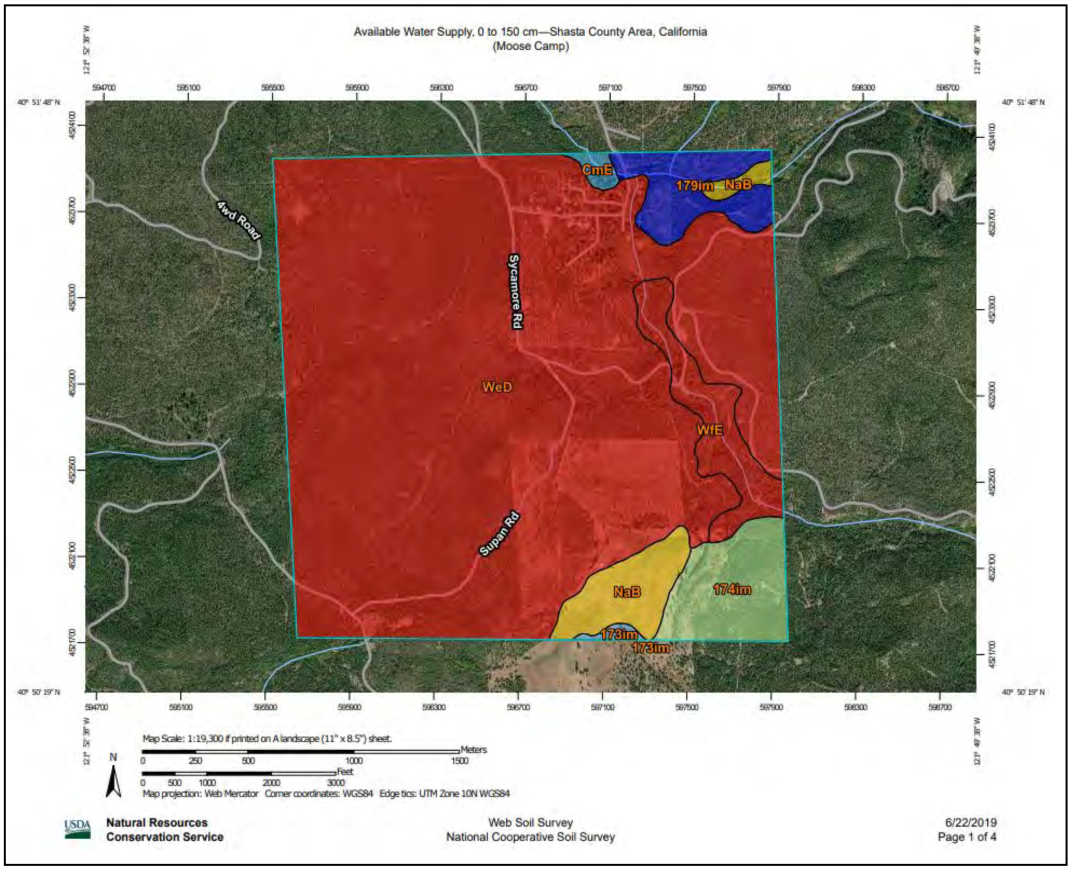

Figure 4.1 Soil types for a portion of the 1992 Fountain Fire near Moose Camp, Ca. Location: 40.851 N, -121.853 W, https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

Table 4.2 Available water storage for several soil types within a unit in the 1992 Fountain Fire.

Table Available Water Supply, 0 to 150 cm - Shasta County, California **Moose Camp**

Map unit symbol	Map unit name	AWS rating (cm)	Acres in AOI	Percent of AOI
173im	Gaspar-Scarface complex, moist, 15 to 30 percent slopes	22.73	3.8	0.3%
174im	Gaspar-Scarface complex, moist, 30 to 50 percent slopes	20.72	67.5	5.1%
179im	Goulder, gravelly sandy loam, 15 to 30 percent slopes	25.20	51.3	3.9%
CmE	Cohasset stony loam, 10 to 15 percent slopes, MLRA 22B	22.36	6.4	0.5%
NaB	Nanny gravelly sandy loam, 0 to 8 percent slopes	13.53	51.4	3.9%
WeD	Windy and McCarthy stony sandy loams, 0 to 30 percent slopes	10.60	1,072.6	81.8%
WfE	Windy and McCarthy very stony sandy loams, 30 to 50 percent slopes	8.92	58.5	4.5%
Total			1,311.5	100.0%

Source: Soil Web Survey . https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

Vegetation

The status of the vegetation for a reforestation project will vary based on the type of project. Reforestation after a timber harvest will be on a 1 to 25 acre unit surrounded by older forest stands. The vegetation for a restoration project will typically be a mix of shrub and grass species currently occupying a site that once was covered in trees. The vegetation after a wildfire will be mainly fire-killed understory vegetation with tree mortality ranging from 0 to 100%. California's public agencies have developed a number of vegetation products that have relevance in describing what tree species have historically been present as well as other vegetation that may compete with new seedlings. The California Department of Forestry and Fire Protection maintains the FVEG system (Fire and Resource Assessment Program 2019), the California Department of Fish and Wildlife has developed a number of wildlife and vegetation map products that may be of value for reforestation projects (California Department of Fish and Wildlife 2019) ,Region 5 of the USDA Forest Service maintains their own vegetation map system (Pacific Southwest Region 2019), the Forest Inventory and Analysis unit of the USDA Forest Service maintains maps based the system of over 5,000 FIA plots (USDA 2019), and other federal agencies collaborated to produce the Ecoregions maps (United States Environmental Protection Agency 2019). Each of these products provides a slightly different product based on different sources of information and projected uses. From a reforestation perspective, the most relevant vegetation products are often related to funding and regulatory issues of the project.

Beyond the large scale mapped vegetation units, ortho-photography and other aerial imagery can be used to do basic vegetation typing in preparation for the on-site assessment. The full color National Agricultural Imagery Program (NAIP) coverages along with other datasets can be downloaded (Natural Resources Conservation Service 2019) and integrated into the project GIS. This imagery will give the forester an initial estimate of what conifers are capable of growing on the site as well as what woody or herbaceous vegetation may be on the site that may become a problem. The species and type of vegetation present will also aid the forester in determining site quality.

Understanding the disturbance history can give valuable insight as to why the species currently present on a site exists there. For example, a past harvest may have removed a dominant over-story of ponderosa pine, leaving the white fir under-story that is drought intolerant to dominate the site. This stand may become susceptible to drought and insect attack long-term. If the forester does not know the stand history, it might be incorrectly assumed that the area is a white fir site and should be replanted to that species rather than to pine species that are more adapted to that site.

A document search prior to going out in the field can also provide valuable insight into the stand's recent history. Timber harvest plans (THPs) are public documents and should be available from CALFIRE's

CALTREES database information system: https://caltreesplans.resources.ca.gov/caltrees/ for any timber harvest activity conducted since 1973. The USFS also maintains timber sale records at the district ranger or supervisor offices of each National Forest. Fire history is mapped for the state by CAL FIRE and the USFS and is available on the FRAP website either as pdf maps, viewers or download of GIS data: https://frap.fire.ca.gov/mapping/. Landowner insights can also be a valuable source of early harvesting history and fire information that may not be captured in publicly available maps or databases.

Silviculture

Before going out in the field, the forester should know what logging and silvicultural systems have been used on the site and will be used in the future. In many areas the historic silvicultural practices will have left major changes to the current vegetation. Historic preferences for higher value species such as pine and a dependence on natural, rather than planted, regeneration have produced mixed conifer stands in many regions with relatively fewer pines and far more white firs compared to what may be a more productive and resilient mix of species. Considering what mix of species is best suited for each reforestation site is an important step for a new reforestation project. The proposed silviculture activity that is planned immediately before the reforestation will affect what condition the unit will be in after logging and what are the necessary requirements for regeneration. Different silvicultural systems, such as clear cutting, shelterwood or group selection, can influence the amount of artificial regeneration required. The type of logging system used significantly impacts the amount of slash generated and hence the potential need for mechanical site preparation.

Sensitive Species and Sites

Any potential issues regarding sensitive sites or endangered species should be researched prior to the on-site field assessment. Potential water quality impacts from excess soil runoff can also a major potential issue for fish and amphibian species. Foresters should conduct an initial assessment using aerial photography, past THP's, GIS, or local knowledge to identify any potential water issues such as sensitive streams, domestic water sources, ditches, ponds and lakes.

Protection of sensitive, endangered and threatened species should be evaluated in planning for any forest management project. Any species listed under federal or state Endangered Species Acts that may occur in the area should be identified. The California Natural Diversity Database (CNDDB), managed by the California Department of Fish and Wildlife, is a required check for getting any project that involves state funding or approval: https://www.wildlife.ca.gov/Data/CNDDB. A QuickView Tool is available for free but access to complete location data entails a fee. Most large organizations and forestry consultants have subscriptions to this service.

The California Native Plant Society (CNPS) provides a database (http://rareplants.cnps.org/) of its Inventory of Rare and Endangered Plants with various search tools for rare plant locations and their status. The CNPS Rare Plant Ranking System ranges from presumed extinct species to limited distribution species now on a watch list. One search tool that is particularly helpful is the “9 Quad search” that provides a list of rare plant species in the nine USGS quadrangle map area around a project area.

CAL FIRE funded or permitted projects (e.g., THPs, Emergencies, CFIP, etc.) require a “Records Check” using the Centers for California History Information System (CHRIS) to determine if known archaeological sites exist in the project area. After records check information has been received, an archeologist or a trained RPF must conduct a field survey of the proposed project area.

Fire Risk

Fire risk is an increasingly important consideration in reforestation planning for a number of reasons. Wildfires are an increasingly significant driver of reforestation needs, especially on federal lands (Starrs et al. 2018) and need to be taken into account when managing the stand for at least 50 more years. Data on the historic impact of wildfires on vegetation as well as future fire risks are relevant reforestation programs in terms of what can be done to increase the probability of survival of the planted trees and the role that trees and other vegetation in creating the fuel loads. Statewide data on fire risk levels can be accessed from CAL FIRE’s Fire and Resource Assessment Program (Fire and Resource Assessment Program 2019). Natural regeneration after wildfires in California is not assured, especially when the fire severity is high (Shive et al. 2018, Welch et al. 2016). Areas with high fire risk are becoming areas that need pre-planning in the event of future reforestation needs (Tepley et al. 2017, Thompson et al. 2007, Zald and Dunn 2018). High fire risk areas are also factors to consider after the seedlings are established with respect to how the future tree density and levels and types of competing vegetation will add to fuel loads and affect future fire behavior. Land managers may want to manage to lower tree densities and patterns of other vegetation to reduce any future fire severity and tree mortality (Kobziar et al. 2009) (Dodge et al. 2019, Zhang Jianwei et al. 2019). It may be desirable to include in the design of reforestation projects in areas with a high and increasing fire probability plans to treat stands of different ages to reduce wildfire mortality (Jain et al. 2019), as well as more explicit permanent fire breaks with limited tree density and control of understory vegetation to limit fuel loads and fire spread over coming decades.

On-Site Assessment

The main purpose of the onsite field assessment is to to verify information that was obtained from other sources and to evaluate critical factors regarding reforestation that cannot be obtained in the pre-site assessment. Field observations cover a wide range of topics and are the foundation of any reforestation plan (Table 4.2). To help facilitate the field assessment, it is a good idea to have some type of site assessment or planning information sheet for each unit such as (Webster 1992) or (Rynearson 2008b). An example of a completed site assessment and project plan, (Rynearson 2008a), is in the appendix along with the examples of site assessment and planning templates.

Locational Attributes

The topographic layout of the units will be important for access, planting activities, and identifying steep or unstable slopes that will need field level evaluations to determine any specific operability constraints and specific actions that will need to be taken during future activities. The area within the boundaries of the reforestation project is the primary focus of the assessment, but some important considerations will require observations of adjacent lands and access roads. The reforestation site should be divided into smaller more homogenous units that will each require a separate set of observations. Accurate acreage is important for reliable reforestation planning and budgeting. If feasible, use a Geographic Positioning System (GPS) to confirm and mark the closest known surveyed corners and identify surveyed property boundaries on the ground. If the project area has poorly defined property boundaries, it may be necessary to have a survey conducted by a licensed surveyor. Acreage for project or unit boundaries can be determined after final flagging and GPS mapping.

Identifying who owns the land surrounding the project site and how it is being managed can help prevent misunderstandings or problems later on. Neighbors are often concerned with aesthetics, water quality, equipment noise, and the use of pesticides so these concerns might need to be addressed during the planning phase. Communicating with neighbors before a project starts could prevent later problems or facilitate helpful mitigations. Neighboring properties can be a source of problems as well. Issues such as wind-throw from recently logged stands, weed encroachment or illegal building across property lines are common issues that may need to be addressed.

Road systems may impact cost, management feasibility and eventual success. Access to the property through other ownerships may require permission or permits and locked gates may restrict access. Identify which roads are permanent, seasonal or temporary on the map. Note the proximity and the type of roads closest to each unit (e.g. seasonal dirt road all the way into unit a few miles from paved county road). Whether roads are rocked or native surfaced can affect access early or late in the season during planting or spraying season when conditions are wet. Check to see if any road work may need to be done to facilitate equipment or vehicle access. Note the aspect and timber cover of roads within the project area. Roads on north faces or that have heavy timber cover, may require snow removal in the spring for planting or spraying access or may require fall planting. Be sure to participate in the harvest planning process so that roads will remain open and usable for reforestation activities after the harvest is complete. Locate all easements, including above and belowground utilities on or near the project site. These sites may need to be avoided by heavy equipment and when planting. It is also necessary to survey for any domestic water uses coming from the subject property as special concern must be taken to avoid any water pollution. Water rights held by others on the reforestation site or illegal water use may also need to be addressed.

Climate Data

Most of the relevant climate information can be obtained before the field visit. However, frost pockets are the one thing that needs to be verified in the field since the relevant topographic patterns that can create frost pockets are often not recognizable from maps. Low, cold, flat areas with poor wind drainage are especially susceptible to frost, especially on the east side of the Cascade or Sierra Nevada Range. Frost pockets will require planting species that are more tolerant to cold conditions. In most cases, this means avoiding planting frost susceptible species such as Douglas-fir seedlings and planting more frost tolerant species such as pine.

Soils Data

Soil types from soils maps needs to be verified in the field. As noted by the NRCS, the soils are mapped at a 1:20,000 scale and may not be accurate for a small number of acres. Don't take for granted that the mapping of soil types is precise enough for a particular unit within the project area. The soil type, texture and percent organic matter will significantly affect residual herbicide efficacy and mobility. Soils should also be evaluated for rockiness to determine the planting method and stock type. The available water storage (AWS) will directly control water availability to the seedlings and other competing vegetation. If the forester is unfamiliar with the soil type, soil samples can be taken and sent into a lab to determine the soil type and texture as well as the percent organic matter. Erodible or unstable areas need to be mapped and mitigation for vegetation management and mechanical site preparation treatments need to be developed for these areas.

Vegetation

The on-site assessment will complement the existing information with more detailed information of the species and condition of competing vegetation, the condition of the advanced tree regeneration in terms of future growth, seeding potential, insects and disease presence, fire history impacts, and other factors. At the site assessment the forester can verify the site quality based on the vegetation present. In addition to assessing the growth rate of mature conifers, site quality information can also be ascertained from the competing vegetation. Poorer sites in California may have a brush complex consisting of buckbrush, whiteleaf manzanita, chamise and yerba santa, whereas higher quality sites may have tanoak, bigleaf maple and deerbrush. The presence of grey pine or Oregon white oak also indicates very low site quality.

The presence of advanced regeneration can affect planting patterns, density, and species choice. Some important questions to evaluate include:

- If there is advanced regeneration, will it be damaged by the logging and is it worth saving?
- Is the advanced regeneration grouped or evenly distributed?
- Does it have at least 50% live crown? Is it growing sufficiently to release?
- Is it infected with a disease such as mistletoe or is it vulnerable to infection by overstory trees not marked for harvest?
- Is it shade tolerant or sun tolerant?
- Will it survive the exposure to sun?
- Will the advanced regeneration have a negative effect on growth and health of a new plantation through competition for sunlight or water?

Another factor to evaluate is whether any natural regeneration might occur on the site. Generally, small group selection units will be within the dispersal zone of surrounding trees and will seed in at least partially, but larger clearcuts and wildfires are more sporadic in scale and density of natural reseeding. If there is a viable cone crop the year of logging, there is a good chance some natural regeneration will occur. Some silviculture methods, such as seed tree or shelterwood cuts, can increase the chance of natural regeneration as seed bearing trees will be left on site for a decade or more. The number of trees per acre at planting can be adjusted lower if significant natural regeneration is likely. The species mix to plant can be adjusted to account for species likely to seed in versus species not likely to seed in.

Some things to consider when developing prescriptions during an on-site visit are: What is the current stand structure? What age classes are present? What is the distribution of species and age class? Will the current residual trees release or are they too old? Is an uneven-age stand worth keeping or is there too much brush in the under-story to create new regeneration? Is it time to start over? With such issues, it is very beneficial for the reforestation forester to be part of the silviculture prescription process to help address them sooner than later.

Detailed information about competing vegetation on the site is essential, particularly the approximate percent cover by species of hardwood, brush and herbaceous vegetation. The type and cover of vegetation on a site can indicate site quality as well as determine vegetation management prescriptions, mechanical site preparation needs, potential animal damage (habitat) and herbicide application techniques required. It is also important to note whether a change in vegetation type will occur once the stand is harvested. Sometimes when a stand is harvested, vegetation that has not been visible on the site for many years establishes itself from the seed bank. Looking at open areas near the current project or for brush skeletons within the project may yield clues as to what vegetation may germinate after logging.

The type of vegetation present on a site will also let the forester know how to treat it. If there is large woody brush in the under-story piling may be necessary. If the brush is low growing and accessible by hand crews, the stand is probably well suited to pre-harvest chemical site preparation. This treatment typically eliminates the need for piling as a site preparation treatment after logging. If conifer production is a desired objective, a mature hardwood component in the stand may dictate that an herbicide treatment (e.g. hack and squirt treatment) is required. It's imperative for regeneration foresters to understand how to deal with not only the vegetation that is present prior to logging but also the vegetation that may show up after the logging operation as some seeds and plants will respond positively to the disturbed conditions. See Chapter 9-"Vegetation Management" for more information.

Silviculture, logging and fire history has a significant effect on conifer and other vegetative species present on a site. The mix of conifer species currently present may not be what was originally there and may not align with landowner objectives. The site visit and assessment should examine the underlying conditions on the site and not just the existing species when determining the species that can be successfully planted.

Silviculture

Foresters need to anticipate how the different silviculture regimes and series of treatments will affect reforestation treatment needs. The reforestation forester needs to be aware of how the stand will be logged and address any potential issues that may affect the reforestation. The method of logging will have a significant impact on how much additional site preparation will be needed. For example, whole-tree logging dramatically reduces slash loads and the subsequent need for piling. In comparison, cable logged units are usually steeper, leave the most branches and tops on site, are covered in post-harvest slash and usually have limited road access – all factors that affect the design and specifications of subsequent site preparation and reforestation activities.

The type of silviculture may also have a dramatic effect on stocking levels, spraying method, mechanical site preparation needs and disease issues (e.g. mistletoe). The site visit is the time to determine what type of site preparation methods will be necessary: chemical, manual, mechanical, burning or a combination thereof. The stand structure, logging method, silviculture and vegetation complex will all contribute to the decision-making process.

Planting requirements, such as scalp specifications, planting method (i.e. hoedad, shovel, auger), and planting stock and density also need to be evaluated at the site visit. The type of silviculture and whether the harvest resulted from a wildfire or green timber sale will affect the number of trees per acre to plant. Slash loading may also affect stocking levels. Seedling stock type and size also need to be addressed at the site visit. Animal issues, wind or sun exposure, rockiness of soil and access will have an effect on planting method and what size and type of stock is planted.

Wildlife habitat is an important ecological and social aspect of forest environments. This term can refer to vegetation type, seral stage, stand structure, or key elements such as snags or large woody debris (LWD). What habitat elements should be retained or encouraged? Important habitat elements to note at the onsite assessment include species and size of snags (especially those with evidence of use), LWD and hardwoods. These need to be balanced with potential impacts to the land manager's objectives and influence on the young plantation. The quantity of each influences fuel loading and future fire risk. Excessive fine fuels are a greater risk than incidental amounts of LWD. LWD can also provide favorable micro-sites for planting.

Sensitive Areas

The on-site field assessment is critical to confirm and evaluate sensitive resources for protection. Hydrologic features such as streams, springs, wetlands ponds and lakes should be evaluated to confirm proper field location and flow or status data. Consultation with the landowner is important to determine if there are any domestic water issues and to confirm if any special buffer zones around these features are required. Determine if there are any domestic water issues such as irrigation or domestic ditches, water lines or wells that need to be protected. Locate and confirm suitability of specific water drafting sources that could be used for spray operations and road dust abatement if needed. When on the site, maintain an awareness of potential sensitive species and confirm their presence if possible. Verify any results from NDDB and CNPS database searches. The archeological survey may be conducted during the site assessment if such a survey is required and has not already been done by an archeologist.

Pests, Insects and Disease

Evidence of animal pests, insects and disease is difficult to collect in the pre-field assessment but can play an important role in the success or failure of reforestation efforts. It is important to observe and document the subtle signs that might give indications of challenges likely to be encountered. See Chapter 10 for more detail on damage. The forester should examine existing vegetation for any evidence of the many species insects that can damage seedlings and young trees. Sometimes problems can be anticipated by observing insect activity in adjacent stands. Prevention of insect problems during seedling establishment is often accomplished by good vegetation management and conifer stocking control. Minimal competition from other vegetation increases tree vigor and the seedling's ability to defend against insect attacks.

Identifying potential pest problems may aid in determining the species to plant. Signs of diseases are often present in existing stands prior to harvest and can sometimes be mitigated. For example, in stands where black stain root disease is present, altering the conifer species has a beneficial effect since the disease is host specific to either pine or Douglas-fir. Dwarf mistletoe, a parasitic plant that reduces vigor, often causes death in the host tree by secondary agents. It is likely to infect the under-story trees and adjacent stands but is also host specific. By altering the species composition to non-host species and removing infected over-story trees, the spread of the diseases can be controlled promoting a healthy future stand. Root rots can be particularly difficult to mitigate. Chapter 11, "Damage" describes the symptoms and treatment strategies of common root rots.

Low site quality can also be an indicator of potential damage from future insect and disease and animals. Trees on lower site qualities are more prone to attack than those on higher quality because the seedlings will be under greater stress. Attacks by insects such as pine tip moth, pine reproduction weevil and pine needle sheath miner are relatively more common on poor sites. In addition, note any obvious existing animal damage to older trees in the vicinity, such as cattle grazing, deer browse, bark removal by bears, and gopher tunnels or gopher related pockets of mortality (See Chapter 11 for a more complete list). Estimate the cover of dead brush skeletons and slash that can be used as hiding and denning cover for rodents and other animals that may increase populations. It is also valuable to note whether the area is in a deer or elk migration or winter range area, as different herbivory patterns can complement competing vegetation control or, alternatively, lead to high seedling mortality (Stokely et al. 2018).

Fire Risk

Mortality from future fires is a great concern for any reforestation project. For reforestation projects after a wildfire or to restore a shrub field that came up after a historic fire, there is strong evidence that the fire risk is high. Before the harvest or vegetation removal in a restoration project is undertaken, the forester should estimate the current fuel loading and how the harvesting, salvage logging, or brush conversion will affect the remaining fuel load. It is important to assess if there is an opportunity to biomass harvest smaller material to reduce the eventual fuel load. This requires a market, operator and suitable topography. Steep slopes will limit the harvest techniques available and cost to treat fuels. Reforestation activities also have the potential to increase or decrease fuel loads as the stand grows and develops (Knapp and Ritchie 2016, Kobziar et al. 2009). As the stand develops, the amount of live and dead fuel within the unit will increase. The reforestation plan can consider actions that would reduce the homogeneity of the fuel load in the developing stand.

Summary

A thorough site assessment, particularly the field site assessment to validate and improve on the pre-field assessment, is critical in the development of the schedule of activities and prescription for a reforestation project. It should provide information on all of the physical and biological characteristics of a reforestation site and the operational and logistical characteristics needed to successfully develop and implement the plan. The final plan will integrate this information with the objectives of the landowner, and the realities of project financing to create a prescription and a schedule of activities for the project.

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References

Balandier P, Collet C, Miller JH, Reynolds PE, Zedaker SM. 2005. Designing forest vegetation management strategies based on the mechanisms and dynamics of crop tree competition by neighbouring vegetation. Forestry: An International Journal of Forest Research 79: 3-27.

California Department of Fish and Wildlife. 2019. Conservation and Management of Wildlife and Habitat. https://http://www.wildlife.ca.gov/Conservation)

Desert Research Institute. 2019. Western Regional Climate Center. https://wrcc.dri.edu/)

Dodge JM, Strand EK, Hudak AT, Bright BC, Hammond DH, Newingham BA. 2019. Short- and long-term effects of ponderosa pine fuel treatments intersected by the Egley Fire Complex, Oregon, USA. Fire Ecology 15: 40.

Fire and Resource Assessment Program. 2019. GIS Data. https://frap.fire.ca.gov/mapping/gis-data/)

Jain TB, Fried JS, Loreno SM. 2019. Simulating the Effectiveness of Improvement Cuts and Commercial Thinning to Enhance Fire Resistance in West Coast Dry Mixed Conifer Forests. Forest Science.

Knapp EE, Ritchie MW. 2016. Response of understory vegetation to salvage logging following a high-severity wildfire. Ecosphere 7: e01550.

Kobziar LN, McBride JR, Stephens SL. 2009. The efficacy of fire and fuels reduction treatments in a Sierra Nevada pine plantation. International Journal of Wildland Fire 18: 791-801.

Kolb PF, Robberecht R. 1996. High temperature and drought stress effects on survival of Pinus ponderosa seedlings. Tree Physiology 16: 665-672.

Lavender DP, Parish R, Johnson CM, Montgomery G, Vyse A, Willis RA, Winston D, eds. 1990. Regenerating British Columbia's Forests. https://http://www.for.gov.bc.ca/hfd/pubs/docs/mr/mr063.pdf.

Natural Resources Conservation Service. 2019. Geospatial Data Gateway. https://datagateway.nrcs.usda.gov/GDGHome_DirectDownLoad.aspx)

Neary DG, Bush PB, Douglass JE. 1983. Off-site movement of hexazinone in stormflow and baseflow from forest watersheds. Weed Sci. 31: 543-551.

North MP, et al. 2019. Tamm Review: Reforestation for resilience in dry western U.S. forests. Forest Ecology and Management 432: 209-224.

Pacific Southwest Region. 2019. Vegetation Classification & Mapping. https://http://www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=stelprdb5347192)

PRISM Climate Group. 2019. PRISM Climate Data. http://prism.oregonstate.edu/)

Rynearson B. 2008a. Reforestation Site Assessment & Project Plan.

—. 2008b. Site Assessment Template.

Shive KL, Preisler HK, Welch KR, Safford HD, Butz RJ, O'Hara Kevin L, Stephens SL. 2018. From the stand scale to the landscape scale: predicting the spatial patterns of forest regeneration after disturbance. Ecological Applications 28: 1626-1639.

Spittlehouse DL, Stathers RJ. 1990. Seedling Microclimate. Victoria, British Columbia: BC Ministry of Forests.

Starrs CF, 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.

Stathers RJ, Trowbridge R, Spittlehouse DL, Macadam A, Kimmins JP. 1990. Ecological Principles: Basic Concepts in Lavender DP, Parish R, Wilson CM, Montgomery G, Vyse A, Willis RA, Winston D, eds. Regenerating British Columbia's Forests. Vancouver, Canada: University of British Columbia Press.

Stokely TD, Verschuyl J, Hagar JC, Betts MG. 2018. Herbicides and herbivory interact to drive plant community and crop-tree establishment. Ecological Applications 28: 2011-2023.

Tepley AJ, Thompson JR, Epstein HE, Anderson-Teixeira KJ. 2017. Vulnerability to forest loss through altered postfire recovery dynamics in a warming climate in the Klamath Mountains. Global Change Biology 23: 4117-4132.

Thompson JR, Spies TA, Ganio LM. 2007. Reburn severity in managed and unmanaged vegetation in a large wildfire. Proceedings of the National Academy of Sciences 104: 10743-10748.

UC Berkeley's Geospatial Innovation Facility (GIF). Cal-Adapt. 2019. https://cal-adapt.org)

United States Department of Agriculture Farm Services Agency. 2019. NAIP Imagery. https://http://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/)

United States Environmental Protection Agency. 2019. Ecosystems Research / Ecoregions. https://http://www.epa.gov/eco-research/ecoregions)

United States Geological Survey. 2019a. Data and Tools. https://http://www.usgs.gov/products/data-and-tools/data-and-tools-topics)

—. 2019b. National Hydrography Dataset. https://http://www.usgs.gov/core-science-systems/ngp/national-hydrography)

USDA. 2019. Pacific Northwest Research Station FIA topics/Inventory Data. https://http://www.fs.fed.us/pnw/rma/fia-topics/inventory-data/)

Webster J. 1992. Unit Planning Information Sheet.

Welch KR, Safford HD, Young TP. 2016. Predicting conifer establishment post wildfire in mixed conifer forests of the North American Mediterranean-climate zone. Ecosphere 7: e01609-n/a.

Young DJN, Werner CM, Welch KR, Young TP, Safford HD, Latimer AM. 2019. Post-fire forest regeneration shows limited climate tracking and potential for drought-induced type conversion. Ecology 100: e02571.

Zald HSJ, Dunn C. 2018. Severe fire weather and intensive forest management increase fire severity in a multi-ownership landscape. Ecological Applications 28: 1068-1080.

Zhang J, Powers RF, Oliver WW, Young DH. 2013. Response of ponderosa pine plantations to competing vegetation control in Northern California, USA: a meta-analysis. Forestry 86: 3-11.

Zhang J, Finley KA, Johnson NG, Ritchie MW. 2019. Lowering Stand Density Enhances Resiliency of Ponderosa Pine Forests to Disturbances and Climate Change. Forest Science 65: 496-507.

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: 425-430.

Appendices

Unit Planning Information Sheet (Webster 1992)

Site Assessment Template (Rynearson 2008)

Reforestation Site Assessment & Project Plan – Saddle Mountain (Rynearson 2008)

Project Plan – Saddle Mountain

Project Photos – Saddle Mountain

Unit Planning Information Sheet

Landowner/Property: ________________________________ Date: ___________________

Unit: ____ Evaluator: _______________

Acres: ____

Aspect & Topography (micro climate, temp. extremes, wind, frost pockets): ________________

____

Soils (site plantability, bareroot vs plug, soil type & texture, slope stability): ________________

____

% Slope (equipment operability):

____

Silviculture method: ____

Tree species present prior to harvest: ____

____

Logging Method: ____

Logging History: ____

____

Fuel Loading (type, amount & distribution, fire hazard vs. plantability): ____________________

____

Wildlife (Endangered species, local deer herds, winter range, summer range, habitat elements, snags, large woody debris, oaks): ____

____

____

Plant Species by % (with current climate, future climate): ______________________________

____

Plant TPA (regulatory requirements, expected survival, desired TPA at first commercial harvest, PCT):

____

Residual Stocking (quality & distribution, seed sources): _______________________________

____

Brush Species Present by % and total cover (successional trends, expected response to vegetation treatments): ____

____

Animal Damage (deer browse, gophers, cattle, etc.): __________________________________

____

Insect & Disease Problems (root rots, mistletoe, etc.): ____________________________

____

Access Issues (road network during needed season, snow, gates, etc.):____________________

____

Site Prep Needed:

Spray (hand or aerial): ____

Pre-harvest or Post-harvest: ____

Foliar or Resiudal: ____

Mechanical (pile, rip, mulch): ____

Burn (broadcast or piles): ____

Planting Timing (early spring, late spring, fall) _____________________________

Thinning Needs (treatment of thinned trees): ________________________________

Neighbors (local concerns): ____

Fuel Loading (tons/acre now, expected over time): ___________________________

Other: ____

____

____

Recommendations: ____

____

____

____

Harvest Vol/Acre:

	PP	SP	DF	WF	IC	Other
% Species:						
% Small/Large:						

SITE ASSESSMENT TEMPLATE

________________________-________________(landowner-tree farm name)

BACKGROUND (*might need to break the following descriptions into separate units with distinct acreage for each, if each unit would have a separate plan of acitivities or cost)*

Legal: T___N R___W or E Sec _____(sub-section:__________)

Acres: approx.________(*suitable & feasible for reforestation project*)

Access: (*proximity of road to unit & type of closest accessible road to unit.; proximity to main county road or highway etc. e.g "seasonal dirt road all the way into unit a few miles from paved county road";also is there legal road access or are right of way permits needed and/or watercourse crossing installation(s) needed etc.*).

____
____
____
____
____
____
____

Survey lines & corner locations: (if feasible GPS closest known surveyed corner/s which might aid in future mapping)

____
____

Easements & Utilities (location of all easements, including above and underground utilities on or near project)____
____
____
____
__________________________ ____
____

Sensitive areas (e.g. streams, springs, Unstable Areas, Arch. Sites, improvements etc.):

____
____
____
____
____
____
____
____

Annual Avg PPT: approx. ____" _____(*avg annual ppt + form of ppt e.g. "mostly snow" etc.*)

Seed Zone: ________

Elev: approx. _______

Slope:________% - _______%

Aspect(s): ____________

Site Class:________________

REFORESTATION SITE ASSESSMENT & PROJECT PLAN

Landowner/Project Name: xxxxxxx / Saddle Mountain Project

Legal: NE¼ NE¼ Section xx and S½ SE¼ SE¼ Section xx, TxxN RxxE.

Acres: 40 (proposed for reforestation)

Access: County paved and then private rocked road to within ¼ mile of unit and then dirt road to within 300' of unit. Need to confirm or obtain easement/ROW from landowners to the west of NE¼ NE¼ Section xx.

Survey lines & corner locations (if feasible GPS closest known surveyed corner/s which might aid in future mapping): No corners or surveyed lines were readily located during site visit. Since project boundary will be close to property line see pre-condition #2 in the following project plan.

Easements & Utilities (location of all easements, including above and underground utilities on or near project): The landowner knows of no easements, including utilities within or adjacent to the project area. No utilities were observed on the site visit or aerial photos.

Sensitive areas (e.g. streams, springs, Unstable Areas, Arch. Sites, improvements etc.): None observed on site visit or on topo maps or aerial photos.

Annual Avg PPT: approx. 20" to 25" (in the form of rain and snow)

Seed Zone: 732 **Elev:** 3,600'-4,200'

Slope: 10%-45% (several steep pitches that flatten off to a benches) **Aspect:** N to NW

Site Class: IV (Dunning)

Soil Type: (NRCS Intermountain Soil Survey) Chirpchatter: very deep (60"+), well drained sandy loam soils that formed in volcanic ash and alluvium derived from volcanic rocks; Soils are stony with large boulders scattered throughout the project area, enough good, deep forest soils to plant most of the area to full stocking with commercial conifers.

Vegetation: Dense, decadent brush consisting of deerbrush (Ceanothus integerrimus), buckbrush (*Ceanothus cuneatus*), whitethorn (*Ceanothus Cordulatus*), greenleaf manzanita (*Arctostaphylos patula*) and squawbush (*Rhus trilobata*). Deciduous tree overstory consisting of 15% canopy cover Oregon white oak (*Quercus garryana*) and 5% canopy cover California black oak (*Quercus kelloggii*). There are large conifer stumps left logging many decades ago in the proposed project area as well as scattered large ponderosa pine trees in brushfields outside the project area but nearby on the same soil type as project area.

General Comments:
The proposed project area is surrounded by several hundred acres of similar brush/oak type on Saddle Mountain that has become well established in what historically was a predominantly ponderosa pine / oak forest prior to logging several decades ago and disruption of the "natural" fire regime (i.e. instead of frequent light ground fires burning beneath an open overstory of large fire resistant pines, keeping brushy fuels low, now fires are less frequent but much hotter, burning decadent brush and relatively small oaks, that rapidly re-sprout and grow into a hazardous fuel load until the next fire). This alteration of the fire regime and vegetation dynamics does not allow for natural ponderosa pine regeneration and/or growth to maturity.

This project would be a good demonstration reforestation project since it would be typical of the hundreds of acres of moderately steep, non-stocked forestland in this vicinity that require management to establish productive native conifer forests again. But prior to contracting for the implementation of the following project plan there are two tasks that would need to be completed:

1. Landowner would need to confirm existence of easement(s) or obtain temporary easement from adjacent landowners (west of project area) to provide general contractor's equipment and crew access to conduct all of the planned operations.
2. RPF would need to obtain survey records and locate all 4 property corners bounding the NE¼ NE¼ Section xx, TxxN RxxE, or the landowner would need to contract with a licensed surveyor to establish those corners and lines if they are not in.

PROJECT PLAN

1. Year 1, Summer: Contract to aerial spray brush and some oaks to kill root systems to facilitate subsequent piling operations and prevent re-sprouting after clearing and planting (this step will facilitate subsequent piling operations as crawler tractors will not have to root out brush and disturb topsoil, but instead just clear enough herbicide-killed brush to facilitate planting operations). Landowner stated that Contractor could use helicopter landing site for loading chemical on Ranch property 1.2 miles NE of the unit.

2. Year 1, Summer/Fall: RPF locate and purchase ponderosa pine (PP) and some Douglas fir (DF) seed (zone 732 elev. 3.5 to 4.0) from CAL FIRE and/or a private timber company and contract w/ Cal Forest Nursery to grow seedlings in Year 2 for outplanting spring of Year 3.

3. Year 2, Summer: Contract to clear & pile, in some areas simply crush, dead brush skeletons with crawler tractor equipped w/ brush rake (do not need complete removal just enough to access ground for planting). Although slopes are steep in some places for tractor piling (up to 45%), having the brush dead for a year will make tractor work for site preparation feasible and not cost prohibitive, with minimal topsoil disturbance.

4. Year 2, Fall: RPF submit Smoke Management plan and obtain necessary permits and burn piles.

5. Year 2, October: Obtain necessary permits & PCA recommendation and contract to broadcast spray 3.5 lbs. Velpar DF per acre on 40 acres.

6. Year 3, January or February (after seedlings lifted and packed at nursery): Transport seedlings from Cal Forest Nursery and place in cold storage.

7. Year 3, March or early April (after snowmelt & soil temperature has reached 42 degrees or higher): Contract to plant 10,000 styro 5 containerized Ponderosa pine and 2,000 stryo 6 containerized Douglas fir on 40 acres at 300 trees per acre (12’ x 12’ spacing)

8. Normally at this elevation and general area we do not net seedlings, but in this case with the surrounding brush habitat for rabbits and the winter deer herd on Saddle Mtn. the site should be closely monitored and if needed install protection netting after planting.

9. Years 4 to 6: Monitor competing vegetation and spray if necessary and funds available from private and/or state cost share sources. Although the pre-harvest foliar spray of current re-sprouting brush on the site, combined with the pre-emergent spray of to control new germinate weeds should greatly reduce the number of follow up sprays needed, it is likely an additional follow-up weed control treatment will be needed in Year 4 or Year 5.

10. Years 10 to 13 (7 to 10 years after planting): pre-commercial thin plantation to 135 trees per acre (18’ by 18’ spacing), favoring any DF that might survive. Even though at PCT age DF will be shorter than PP, within another 10 years DF should equal or exceed PP growth. Also, where present, thin black oak stump sprouts to 2 or 3 stems per clump.

REFORESTATION SITE ASSESSMENT & PROJECT PLAN

Brushfield in the proposed project area pictured in the foreground.

Large healthy ponderosa pines and sugar pines on a nearby site with the same soil type and precipitation as the proposed project area.

Illustration of Oregon white oak sprouts that cover approximately 15% of the proposed project area that along with dense brush will prevent natural establishment of shade intolerant conifers that are adapted to this fire prone site with relatively low annual precipitation .

Chapter 5:
Seeds

Teri Griffis, CA Department of Forestry & Fire Protection (Retired)

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Introduction

Successful reforestation is highly influenced by seed origin and seed condition. This chapter summarizes the best practices for planning, collection, processing and storage of seed collected from trees in natural stands as well as trees in tree improvement programs. It is essential to use genetically diverse, high quality, local seed and seedling stock that is best adapted to the planting site to ensure long-term success. Conifers are long-lived and must contend with all of the various physical and biological factors and hardships contained within the ecosystems in which they have evolved. Natural selection results in the accumulation of an enormous range of adaptive genes over time. An individual organism's genetic make-up is its genotype. Each tree species responds in its own way to local environmental conditions such as extreme heat or cold, moisture stress, aspect, soil type, and competitive pressures. An organism's phenotype is the combination of observable physical characteristics as determined by its genes from both parents and interaction with the environment. However, it is the maternal parent's phenotype one observes when choosing seed trees for cone harvesting in open-pollinated stand collections.

Superior quality, locally adapted seeds produce vigorous seedlings that become better established; over time they will out-compete surrounding vegetation for moisture, nutrients and space and occupy the site more rapidly. As noted in the 'Tree Improvement' section of this chapter, improved seed produced from seed orchards supported by tree improvement associations and cooperatives in California combine the benefits of genetic improvements, strict quality control, and well-tracked genetic and locational information. When improved seeds of the desired species are not available from seed orchards, wild seeds collected and stored in seed banks will be the primary source of seed for reforestation projects. A successful and timely response for reforestation requires meticulous planning, collection, processing, and storage considerations to ensure that appropriate quantities of seeds of documented origin are available when they are needed. Conifer seed production and quality are highly variable from year to year and should be sufficiently evaluated before collections are initiated. It is the irregular nature of tree seed crops that necessitates storing large quantities of viable seed when it is available, for use during the potentially long stretches of poor seed production. Low quality seed crops do not generally warrant the costs and time that will be invested in seed procurement and seedling production, however special consideration may be necessary for species or areas of high conservation concern. This chapter describes the many factors that must be considered to ensure that collections are successful and that seed quality is maximized.

A key objective of the text is to review the relationship between seed maturity and seed quality. Many of the concepts presented here have been accumulated from generations of forest resource scientists, geneticists, and conifer seed specialists and are considered common knowledge for the genre. The writers add their collective personal experience with cone and seed planning and collections, seed processing (cleaning and upgrade), and testing and storage to illustrate specific topics in the discussion.

Rapid climate change caused by human activities is changing forested environments. Reliance on long-standing seed transfer guidelines is necessarily being re-examined. Climate predictions in this century strongly suggest that reforestation practices moving forward should favor tracking both current and modeled future climates in making seed transfer decisions. Broadly adapted seed sources are key to mitigating some of the challenges posed by climate change. Tree improvement programs offer forest resource professionals management options that promote adaptation and resilience in rapidly changing environments. (See Tree Improvement section at end of this chapter.)

Importance of Seed Origin

The success of any reforestation effort is dependent on the origin of the seed and its quality and condition. Seed origin is important because trees are locally adapted to the numerous characteristics of the environment they are naturally growing in. However, ongoing changes in forest climate conditions require explicit decisions on matching seedlings to the climatic conditions that the trees will face over coming decades. A key insight coming out of Douglas-fir seed source research across California, Oregon, and Washington has been the need to focus on “climate space” rather than “geographic space” as some of the key variables have been minimum winter temperature and maximum summer aridity, rather than simply latitude and longitude (Harrington and St. Clair 2017). In practical terms in California, this means a greater focus on the aspect as well as elevation where the seeds (or scions used in seed orchards) were collected rather than the seed zone number that often covers large elevation ranges in California. While California does not have as sophisticated a seed transfer system as the one recently developed for British Columbia (O’Neill et al. 2017), there is ongoing research across the Pacific States to build on forest genetics research to positively respond to new challenges (St. Clair and Howe 2017).

Development of the California Seed Zones

Foresters have long recognized that California’s climate, topography and geology are very diverse and that these differences in the environment are significant to the productivity of a forest site and survival of the many tree species that are found there. This complexity resulted in the establishment of the California Tree Seed Zones (Fowells 1946) with revisions by Roy (1963) and Schubert (1966). In 1970 the Forest Tree Seed Committee (Buck et al. 1970) revised the original zones and restructured the recording system. It is this version of the California Tree Seed Zone map that is still in widespread use today. In addition to recognizing the vast topographic, climatic, and edaphic differences of the landscape, seed zones are meant to inform seed transfer decisions from the seed collection source to a specific planting location with minimal risk of maladaptation.

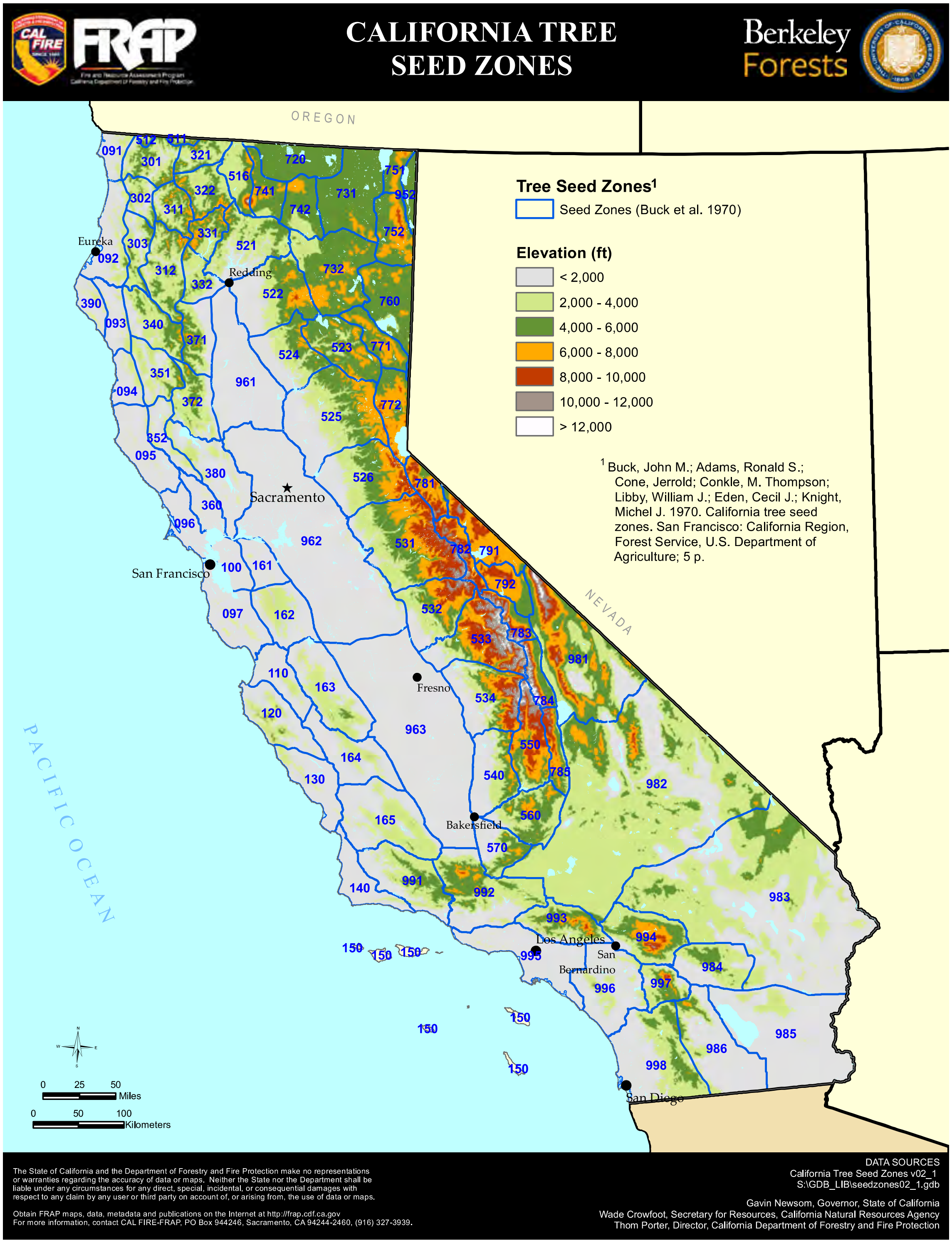

Figure 5.1 California Tree Seed Zone Map.

The state is divided into six major physiographic and climatic regions, thirty-two sub regions within these, and 85 Tree Seed Zones that are separate and unique (fig. 5.1). Plant associations within each region change as one moves from north to south, west to east and from low elevation to high elevation. In zones where climate and topography are more variable "local" generally implies the same microenvironment i.e., areas within the same drainage or those having the same aspect or elevation. Within the individual zones, conifer seed collections are catalogued by separate elevation bands with every 500 foot rise in elevation. The system of using seed zones and elevation bands to delineate areas of plant adaptation is used in California as well as many other states.

Main Features of the Physiographic and Climatic Regions

090 series – North Coast Redwood belt – extends along the coastal fog belt, approximately 5 to 30 miles in width, from California's northern border south to Monterey Bay. The belt lies slightly inland avoiding direct oceanic influences. Precipitation is plentiful in winter and summers are moderated by frequent fog. North of Cape Mendocino forest productivity is generally higher and associate conifers include Douglas-fir, grand fir, Sitka spruce, western hemlock, Port-Orford cedar and western redcedar. West of the redwoods, beach pine forest dominates on shallow, sandy soils. South of Cape Mendocino is predominantly lower site and redwood mixes with Douglas-fir and remnant patches of Bishop pine and grand fir. The isolated Cape Mendocino area (sz 390) is not in the 090 series because it has unique topo/climatic elements that preclude oceanic effects and cooling fog and therefore, does not support redwood.

100 Series – Central Coast – encompasses the coastal ranges from the Sacramento-San Joaquin Rivers south to Santa Barbara and includes the Channel Islands. The Pacific Ocean is the chief influence on temperature and moisture the area receives. While the southern extent of the range for coast redwood and Douglas-fir is found near Big Sur on north facing slopes and in drainages fed by summer fog, the central coast is predominately a mix of disjunct stands of closed-cone pine and cypress groves. The region also contains a series of valleys with elongated ridges that are parallel to but inland from the coast; the flat San Joaquin Valley borders on the east. The inland region is decidedly warmer and drier than areas west of the coast range. However, where the mountains intercept Pacific moisture in steep drainages, pockets of ponderosa pine, sugar pine and Santa Lucia fir can be found. Coulter pine is present at higher elevations with foothill pine and oak woodlands dominating the east-facing foothills and valley floors. The inland southern mountains and valleys are considered semi-desert and support an arid plant species mix.

300 Series – North Coast interior – extends from the summit of the Siskiyous south to San Francisco Bay and lies between the coastal fog belt and the Sacramento Valley. The western edge of the region lies in the rain shadow of the coast range and overall the climate is Mediterranean with winter rains and summer drought. The area supports a wide variety of conifer forest, woodland and prairie that differs considerably with topography, parent material, precipitation type and amount, and elevation. Indeed, the region has the largest number of sub-regions of any region. It also includes an isolated zone (390), located on the coast at Cape Mendocino which is predominately Douglas-fir.

500 Series – Western Slope Cascades and Sierra – an extension of the west slope of the Cascades in Oregon south through the Sierra Nevada to the Greenhorn Mountains in Kern County. It is bounded by the foothill belt of the Central Valley to the west and the crest of the Cascades and Sierra Nevada to the east. The region supports a rich diversity of conifers, though species occurrence on the landscape is highly dependent on latitude, elevation and aspect. These gradients define the temperature and precipitation type, the depth and duration of snowpack, and the length of the growing season. The lowest elevation conifer is foothill pine where it intermixes with the oak woodland type. The lower montane mixed conifer forest is dominated by a fluctuating mix of Douglas-fir, ponderosa and sugar pines, white fir, incense cedar and associated hardwoods. It is worth noting that, moving south of the Mokelumne River (526/531 border), Douglas-fir occurrence begins to decline. The upper montane contains the red fir forest type as pure stands or mixed variously with white fir, Jeffrey and western white pine, mountain juniper woodland, and well-defined groves of giant sequoia. Wetter habitats tend to support lodgepole pine. The subalpine type above 8,500 feet consists of a mix of slow-growing and scattered white pine and mountain hemlock associations.

700 Series – Modoc Plateau, Eastern Slope Cascades and Sierra - an extension of the east slope of the Cascades in Oregon south through the Sierra Nevada to Walker Pass in Kern County. The Warner Mountains mark the northeastern boundary of the region. The environment is character-istically warm and dry as it lies within the rain shadow of the southern Cascades and northern Sierra Nevada. The open plains and southern Cascades sport volcanic basalt and porous soils, in comparison to the granitic substrate of the Sierra Nevada. The northern reaches of the southern Cascades consist largely of white fir, Douglas-fir, western juniper, and disjunct groups of ponderosa and Jeffrey pine with a minor incense cedar component. Shasta red fir and Jeffrey pine forest join the mix on the western edge above 5,500 feet elevation. East of the Sierra Nevada (north and south of and including the Lake Tahoe basin) red and white firs, Jeffrey, lodgepole and white pines dominate in the higher elevations with western hemlock, while the singleleaf pinyon-juniper woodland is found below 5,250 feet. The most common forest vegetation in the Southeastern Great Basin is the limber pine forest with a lodgepole pine component and the whitebark pine subalpine type in the higher elevations. Trees growing here are adapted to a severe, cold-dry climate.

900 Series – Four Separate Areas – a 'Catchall' series:

950 – Great Basin: a high elevation desert valley in the far northeastern corner of California east of the Warner Mountain range, extending south from the Oregon border to Lower Alkali Lake.

960 – The Central Valley: bounded by the northern edge of the Sacramento Valley in the north to the base of the Tehachapi Mountains in the south. Natural vegetation includes grasslands, marsh, prairie, chaparral, and riparian and oak woodland habitats.

980 – Southern California Desert region: in far southeastern California. It encompasses the Mohave and Sonoran-Colorado deserts. Vegetation in the region is highly diverse but mostly devoid of conifers.

990 – Southern California Mountains: an area which comprises most of the natural conifer stands found in Southern California – a high elevation mix of mostly Jeffrey, sugar, ponderosa, coulter, and pinyon pines, white fir, incense cedar and a variable bigcone Douglas-fir component. A particularly challenging environment inland, winters are cold but relatively dry. The long droughty season is especially hot with frequent harsh, drying winds. Shallow soils and low precipitation are limiting factors for growth and survival of montane forests in the region. Three species of cypress: Sargent, Cuyamaca and Tecate, occur in the region in very small and widely scattered populations. They are naturally fire adapted but are increasingly threatened with post fire establishment failure in the wake of recurring human caused and climate driven conflagrations. The sub-alpine forest above 7,800 feet supports lodgepole, pinyon and limber pines and western juniper where temperatures remain low and snow persists well into summer.

Labeling Seed Zones and Elevation Bands

The numbering system for the tree seed zones uses a 3-digit designation, XYZ. Two digits follow the decimal and identify the 500 foot elevation band, XYZ.00.

Example: 500 feet = .05; 4000 feet = .40

X = Denotes major geographic areas having similar topographic, climatic and edaphic environments. **Physiographic and climatic regions**.

Y = Divisions within the major regions representing more localized topographic, climatic and edaphic environments. **Physiographic and climatic sub-regions**.

Z = Zone number –If Z is a number 1 through 9, then it is an arbitrary division of a sub-region to keep seed zones about 50 miles in latitude. If Z is 0, this is a unique zone and the zone is considered a sub-region.

Example: 340.15 – 3YZ represents the 300 series, or North Coast Interior physiographic and climatic region. 34Z represents one of the 17 sub-regions in the 300 series. 340 is a unique zone and therefore, a sub-region itself because there are no other 34Z zones. The .15 indicates an elevation between 1,001 and 1,500 feet.

Example: 526.45 – 5YZ represents the 500 series, or West Slope Cascades/Sierra physiographic and climatic region. 52Z represents one of the seven sub-regions in the 500 series. 526 is a zone, an arbitrary unit of the 52Z sub-region, in this case, the most southern zone in the 52Z sub-region. The .45 signifies an elevation between 4,001 and 4,500 feet.

The seed transfer guidelines, in use since 1970, served forestry professionals well for nearly 40 years but they assumed long-term environmental and climatic stability. Historically climate cycles have changed over millennia, century and decadal time frames and species have adapted by shifting ranges and adjusting, over considerable time, through genetic change (Rosenthal, Millar 2003). Science indicates that global climate change is currently accelerating more rapidly than in the past due to human influences. Such rapid changes demanded a review of the existing paradigms. New research-based seed movement guidelines were implemented in 2010 by the USDA Forest Service that may help to promote resiliency in a changing environment and are presented here:

Seed Transfer Guidelines

These guidelines modify the 1970 guidelines (Buck et al. 1970) based on ongoing research by the USDA Forest Service.

- Use source identified seed only – accurate and detailed seed collection records are key.
- Deploy forest reproduction materials, within a seed zone, upslope from source origin a minimum of one elevation band (500 feet) to 1000 feet upslope.
- Deployment of forest reproductive materials downslope from source origin is disallowed.
- Seed from an immediately adjacent seed zone (from south to north only) within the same physiographic and climatic sub-region (same XY) is considered compatible if the environmental conditions are similar. Use the closest available seed.

- Seed movement great distances is an uncertain solution, but if source origin is within 100 miles, not unreasonable (photoperiod changes more quickly at higher latitudes). (See inset for information about the Seed Lot Selection Tool, SST).
- Distance moved from source origin should consider whether the species is a generalist or a specialist in adaptive traits.
- Forest managers are encouraged to increase use of improved genotypes - improved genotypes from tree improvement programs are generally more broadly adapted and pest resistant and can be moved farther in both distance and elevation.
- Forest managers are encouraged to add a more diverse species mix and broader genetic base of a given species to account for climate uncertainties over the life of a stand.
- Forest managers are encouraged to use a <u>mixture</u> of seed sources that may be better adapted to the temperature and moisture extremes that are predicted in the next few decades.

Aitken and Bemmels (2015) suggested that the potential maladaption of trees to climate change could be addressed by choosing seeds from other regions with climates that match predicted future conditions. They further suggest that provenancing multiple seed sources to increase diversity and buffer against future climate uncertainty should be included in such as strategy.

The discussion about climate change and forest adaptation is in flux. Climate-driven changes necessitate that trees and forests adapt to new climatic conditions and environments. Forest resource professionals need to remain flexible when making deliberate seed transfer decisions. Genetic diversity is key – broad mixtures of species and sources that may be better adapted to future conditions may offer resilience in shifting environments.

Climate change mapping tools that support decisions on moving plant material across environmental gradients are becoming more readily available. These mapping applications are designed to assist with matching alternative seed sources with planting sites using selected climate variables. The main objectives are 1) given a planting site, what seed lot(s) will work or 2) given a seed lot, where on the landscape is it best suited for survival.

> ***<u>The Seedlot Selection Tool</u> (SST)*** *is one web-based mapping tool that was designed, through a collaborative effort, by the USDA Forest Service, Oregon State University, and the Conservation Biology Institute. The goal of the SST is to help resource managers match seed lots (seed collections from a known origin) with appropriate planting sites based on ensemble models of current as well as predicted climate change projected across the landscape. This approach assumes that plants are adapted to the climate where they are currently found, however other important factors such as physiographic, edaphic, aspect/slope and competitive environment are not considered. Inputs allow users to select transfer limits, climate scenarios, and a set of climate variables. While the results from this tool are subject to the uncertainties and limits of such predictions, users can explore and compare the output derived from different selected variables to gain an understanding of how climate variation is distributed across a geographic area.*
> ***<u>https://seedlotselectiontool.org/sst/</u>***

Future Climate Projections

Future climate scenarios are inexact but largely forecast a rise in temperature and changes in the amount and distribution of precipitation across the state (Fire and Resource Assessment Program 2018). Mean annual temperature is expected to increase in all ecological regions but the magnitude of temperature rise will vary by region; less near coastal environments and greater increase inland. While climate models and forecasts differ, a moderate range of increased warming from +2.5 to 4.6^{o}C in Northern California is projected between 2000 and 2100 (Barr et al 2010). These projected increases are creating uncertainty about long-term forest tree adaptations and response to novel climates. There is widespread agreement that climate threats in California will include accelerated heat and drought (though some regions are projected to be warmer and wetter), increased fire frequency and intensity, and an increase in ancillary stressors such as insects, disease, and inter-species competition. As temperatures rise, more precipitation is expected to fall as rain rather than snow resulting in diminished water reserves in the Sierra Nevada. Less snow pack and earlier snow melt will result in increased flood events during winter and spring causing more soil erosion and less water availability for forest plants during the lengthy dry period (Fire and Resource Assessment Program 2018).

Greater climatic variability and uncertainty is expected to create serious implications for future tree health and cone production. It may be necessary to collect from a greater number of parent trees over a wider area than current standards require in order to capture as much variability as possible. The climate gradients that define an environment as compatible for a given population of trees are changing. Climate warming will impact winter minimum temperatures, summer maximum temperatures and the number of frost-free days. The impacts on bud set and bud flush are anticipated but will likely vary based on the biology of the species. As the rate of climate impacts increases, many trees may not adapt to the changed conditions fast enough and may be vulnerable to failure (Fire and Resource Assessment Program 2018). Tree communities located at the lower elevations or the southern, drier margins of a species range will likely show signs of decline first. In general, range expansion is expected at the leading edge (northern latitudes and higher elevations), with species' range contraction occurring at the trailing edge (southern margins and lower elevational limits).

In California, one current challenge is to prioritize collections of existing foothill and other low elevation seed sources as a hedge against loss of habitat type. In addition to potential genetic maladaptation to future conditions, foothill plant communities with limited moisture and high fire risk are especially vulnerable to loss of species abundance and distribution due to a variety of human caused factors. These include urban encroachment, fragmentation, overgrazing, past logging and mining activities, conversion to agriculture and increased fire and insect activity. Furthermore, these low elevation conifers are currently found in relatively hot and dry environments - they may have adaptations that will be valuable for planting out in a range of landscapes with future similar environments.

Biology

Cone and Seed Development

In conifers, cone and seed production involves four principal stages: the formation of reproductive buds, the development of male and female strobili (pollen and seed cones), pollination and fertilization, and seed maturation.

Bud initiation occurs each spring, but development into vegetative or reproductive structures depends on a variety of factors including environmental conditions, biological processes, and position on a branch. Bud differentiation takes place throughout the first growing season and is generally apparent by fall of the first year. The general appearance of the bud and position on the branch or part of the crown are indicative of bud type. Female (seed) cones are generally wider at the base, longer than male and vegetative buds, and are terminal or sub-terminal in position. Male (pollen) cones are generally laterally positioned and often found on undersides of lower branches in the crown. Under favorable weather conditions (dry, sunny weather in spring) and high nutrient status, a higher percentage of buds will become reproductive and fewer are likely to abort or become latent. The difference between an abundant cone crop and a poor one is more likely the result of the number of buds aborted rather than the number of buds produced in a given year.

Impediments to Formation and Development of Reproductive Buds

Impediments in this time period are thought to be unfavorable weather, timing of frost, and poor tree nutrition. While flowering can increase in trees under moisture stress, persistent drought conditions lead to decreased shoot growth, reduced crown development, and increased bud failure. Good nutrient status and greater light intensity favor good seed crops; therefore irrigation and fertilizer applications in seed orchards or seed production areas (SPAs) can promote bud development success. Additionally, thinning treatments in orchards and SPAs increase light intensity and reduce competition for moisture and nutrients for desirable leave (seed) trees.

In late fall reproductive buds slow their metabolic activity, becoming nearly dormant, but still undergo internal changes through winter. They resume active growth and burst the following spring when pollination (and for some species, fertilization) takes place – this is year two, the “cone development” year. The male pollen cones elongate rapidly and swell, then split open as they dry and release pollen grains into the wind (fig. 5.2). Nearly simultaneously the female seed cones elongate, causing the immature bracts to spread apart slightly and allowing the airborne pollen grains to enter. Upon capture by a receptive female cone, the pollen grains drift down the scales toward the ovules at the base of each scale and the female cone scales and bracts close again (fig. 5.3). In most species, with the exception of true firs which remain upright in the uppermost branches of the crown, the seed cones become pendant and pollination is complete (fig. 5.4).



Figure 5.2 (left) Male pollen cones *P. ponderosa*. **Figure 5.3** (center) Female cone *P. ponderosa*. **Figure 5.4** (right) Spent cone and pendant first year cone *P. menziesii*. *Photo:* Mary Ellen Harte.

Because conifers are wind pollinated, factors affecting success in this time period are mostly weather driven. Therefore, conditions of frost, drought, excessive wind, lack of wind, and excessive rainfall all have a strong influence on pollination success or failure. Losses can occur after pollination as well if temperatures become extremely low causing cones to abort. In instances when there is low pollen flight or mixing, self-pollination becomes a factor that can contribute to embryo degeneration or low vigor. Additionally, pollen viability, which can vary from one day to two to three weeks depending on species, and female cone receptivity may differ in timing, duration, or both in some years and further effect pollination success. With all of the variables involved at this early stage of cone development, it is difficult to predict in advance whether the end result will be a collectable crop of a given species in any given year.

Within the female cone, the pollen grains germinate and each will produce a long tube; one pollen tube penetrating a single ovule. After a series of cell divisions, fertilization occurs when a single sperm cell fuses with an egg cell. The time period for this process varies greatly by species and conifers generally fall into one of two categories: 2-year or 3-year species. For 2-year species fertilization closely follows pollination, usually within weeks, and cones develop through summer and mature in late summer or fall. For 3-year species the female ovule continues to grow slowly through the next winter while development of the pollen tube stops in mid to late summer; fertilization occurs the following spring and cones mature in the fall of the second year after pollination (approximately 15-16 months later). The cypresses comprise a third category and are mature after the embryo emerges from a dormant phase and resumes maturation in the year after fertilization for a total reproductive cycle of approximately three and one-half years.

Post-fertilization growth includes enlargement of the female cone and differentiation and maturation of the embryo within the female gametophyte (megagametophyte) or food reserve. The embryo has all of the necessary structures and genetic information to grow into a miniature plant; a radicle (primary root), hypocotyl (stem), and cotyledons (first leaves). The seedcoat protects the inner structures and may be thin, soft and papery as in true firs and incense cedar, or thin to thick and woody as in pines, Douglas-fir and juniper. In some species with especially hard seed coats, such as several species of pine and cypress, the seed coat may also restrict water uptake, gas exchange and emergence of the radicle and require treatment before germination can occur.

True firs, incense cedar, western red cedar and hemlocks have resin pockets in their seedcoats. It is thought that these resin vesicles protect the embryo from excessive drying and play a role in seed dormancy. Seeds with resin vesicles must be handled very carefully as these structures are easily damaged which may result in poor quality or death of the seed. The megametophyte surrounds the embryo and provides the nourishment necessary for initial growth of the embryo. Most conifer seed is winged which facilitates movement from the tree during dispersal; some wings are affixed lightly and are easily removed as with most pines while others are an integral part of the seed coat, as in true fir, Doulas-fir and incense cedar. Moisture reduction is the final stage of maturation before natural seed shed. This drying allows the seed to enter a quiescent period necessary for the synthesis of many enzyme systems including those required for seed dormancy and desiccation tolerance.

Impediments to Cone and Seed Development

Insects

Insects that feed on cones and seeds of forest trees can have a significant impact on reforestation planning. Included are various species of cone beetles, cone worms, moths, maggots, chalcids, and true bugs. For most conifers, cone and seed production is highly variable from year to year, producing moderate to heavy crops only periodically, interspersed by several years when seed production is low to scarce. This periodicity varies among conifer species so the size of insect populations can fluctuate wildly based on food supply from year to year. If there are back to back good crops, insect populations may increase and the second crop can be severely damaged. Likewise if a poor crop follows an abundant one insect populations will decrease or disappear and the subsequent crop may be insect-free.

Figure 5.5 (left) *Dioryctria spp*. feeding on buds of *P. ponderosa*. **Figure 5.6** (center) Pitch response on *P. menziesii* from *Barbara spp*. **Figure 5.7** (right) *Leptoglossus occidentalis* on white pine. *Photo*: Sandy Kegley, USDA Forest Service.

Insect activity may be minor or the damage to developing cones and seed can be severe. Early damage may be caused by defoliators that eat buds and foliage at the earliest stages of development (fig. 5.5). The spruce budworm, *Choristoneura spp.*, can decrease the quantity of pollen buds available and girdle female buds at the base causing them to abort. Cone beetles, *Conopthorus spp.*, kill developing cones by boring into the stalk – the conelets become brown and casehardened and cease development. Later damage occurs in developing cones by cone worm and cone moth larvae that hatch from eggs deposited onto the scale during pollen reception or from larva that bore through the cone scale or axis and consume the seed contents (fig. 5.6). The Western conifer seed bug, *Leptoglossus occidentalis,* feeds on conelets as nymphs and causes later damage to developing cones by the adult when it pierces the cone scale and extracts the seed tissues with its sucking mouth parts, causing the contents to collapse (fig. 5.7). Cone scale and cone gall midge activity deforms cones; this damage fuses the developing seed to the scale leading to extraction difficulties. Seed worms and chalcids may cause extensive damage to cone interiors but often go undetected because the cone may continue to develop normally. These losses are usually discovered only after samples are collected for quality and maturity assessments later in the summer.

Management strategies to control insect populations in native forest ecosystems are generally uneconomical but are feasible in seed orchards or seed production areas. Maintaining healthy trees and employing sound sanitation practices is key. Dead and injured branches should be pruned and destroyed. Stressors, such as soil compaction from equipment and competition from weedy vegetation, must be reduced as much as possible. It is very important to keep the orchard free of over-wintering pests by removing and destroying unharvested and spent cones on the ground that could usher damaging insect and disease pathogens into the following season.

Pathogens

There are several important pathogens that can adversely affect cones and seeds of conifers in California. One type is Sirococcus blight, caused by fungal spores that are ever-present and can spread to new shoots and cones in the spring. Infected seeds often have shrunken and discolored contents and the seed-borne inoculum results in a diseased seedling when exposed to favorable conditions for growth and spread during germination. *Sirococcus spp.* fungi become established in seed lots when older cones are included in the harvest and can contribute to seed deterioration and subsequent losses in nursery operations. Improved cultural practices over the years such as strict avoidance of squirrel caches, spent cones, and ground collections all have contributed to a significant reduction in the collection of *Sirococcus* diseased cones and seed.

Western gall rust, *Endocronartium harknessii*, is a disease that causes branch and stem galls on California pines. These galls can cause severe damage to cone bearing branches and result in cone and scale distortions in the following; knobcone, lodgepole, coulter, bishop, and Monterey pines, where the cone base and peduncle come into contact with the stem.

Pitch canker, *Fusarium circinatum*, is an introduced disease and is present in the coastal areas of California less than 75 miles inland from San Diego County in the south to southern Mendocino County in the north. Pitch canker is a highly virulent pathogen common to knobcone, bishop, and Monterey pines but is also found on other pine species. Because infections can include reproductive stages as well as vegetative, collection of cones and seeds of these species must remain local to avoid introductions of the disease into other areas of the state.

Some seed borne pathogens such as *Aspergillus, Fusarium, Mucor* and *Penicillium* may simply be indicators of poor seed quality rather than being the cause of deterioration. These agents may colonize seeds as a result of adverse environmental conditions such as high temperatures or moisture conditions, or physical damage due to improper handling during collection, transport, storage or during the extraction and cleaning processes. These fungi can infect seeds internally destroying the embryo and megagametophyte, or externally on the seed coat affecting seed germination when they cause damping off or root rot in the nursery. Disease development is also strongly affected by the degree of cone and seed maturation attained before cones are collected. Research has shown that seed viability and seed storage capacity decline when cones are not allowed to properly mature on the tree.

Sudden Oak Death, *Phytophthora ramorum*, is a disease that has killed countless oaks and other forest species since the mid-1990s. It also causes Ramorum blight, a twig and foliar disease in many other plant species including coast redwood and Douglas-fir. *P.ramorum* thrives in cool, moist environments and in California is currently limited to coastal evergreen and tanoak/redwood forests. It is a federally quarantined pest resulting in regulated or restricted movement of host material out of the zone of infestation (ZOI) to uninfected areas of the state or out of the country. Researchers have found that inoculum is not present on the cones or seeds of the conifer host species. Consequently, collections of Coast redwood were successful in 2008 in Santa Cruz County, and in 2009 in Mendocino County, albeit with strict sanitation precautions in place. The redwood cones were removed from the top half of the crown, “clipped in place” on site at the base of each cone to remove all green material, needles and twigs and transported in sterile cone sacks to the processing facility.

Mammals and Birds

Activities by mammals and birds may also cause loss of cones and seeds. By far the greatest losses are attributed to squirrels and chipmunks which collect and cache large quantities of ripe and unripe cones of pine, true fir and Douglas-fir for winter retrieval. A squirrel cache is a damp and decayed environment with a high level of diseased seed and debris. In addition, the cones and seeds that comprise them are from unknown parent trees, making these caches totally undesirable for collection purposes. Squirrel feeding can destroy 50 to 90 percent of a cone crop in some years. For high value trees, removing the lower branches and installing metal banding around the stem and increasing tree spacing to avoid crown to crown migration are known to significantly reduce damage by these agents. Mammals may also cause minor damage by feeding on cambial tissues, destroying buds and flowers – ponderosa pine is a favorite. Many bird species also feed on and cache developing and mature conifer seeds. While caching plays an essential role in seed dispersal and tree establishment, damage can be serious for collections when birds feed in flocks. Larger birds such as the Lewis's woodpecker, Steller's jay, and Clark's nutcracker mine through cones which may leave large damaged areas that cause significant seed loss and difficulties with extraction.

Humans

If cones are harvested too early, in most cases the maturation processes are interrupted and seeds cannot develop properly. Green cones and seeds are very high in moisture content and they will dry too rapidly if picked too soon. Research has shown that "drying on the tree" is necessary for the seed to enter the stage required for desiccation tolerance and germination when rehydration occurs (Bewley, Black 1994). The internal tissues have not completed the normal accumulation of storage food reserves and these reserves are insufficient when the connection to the parent tree is broken. Other impediments caused by human activity may be direct or indirect but all can create an unhealthy environment for growing trees. These include increased emissions and air pollution from urban areas, compaction of soils from overuse, and the myriad impacts realized as a result of climate change.

Cone Bearing Age

Conifers are slow growing, long-lived trees and the length of the juvenile period is extremely varied in the temperate zone. The majority of species may begin flower production at 8 to 20 years of age but likely produce only one sex or exhibit only intermittent flowering. It is generally many more years before conifers will reach cone bearing age (the age at which significant quantities of viable cones and good quality seed are produced) and become prolific producers later still. A dominant Douglas-fir, for example, may produce cones at 20 to 25 years of age but trees 80 to 100 years+ generally have many more viable cones per tree. There appears to be a tendency for earlier cone production on high sites. In most conifers there is strong correlation between tree size, crown position, vigor and cone production. Good cone production is generally best among dominant, young-to-mature vigorous trees with wide crown width and pointed top. These trees receive more sunlight from all sides. Cone production then tends to generally drop off as trees become over mature; this is true of ponderosa pine, sugar pine and true fir. However, in one study of the differences in cone production among different age classes of *Sequoiadendron giganteum*, it was found that the oldest age cohort (individuals 1,000 to 3,000+ years of age) consistently produced greater quantities of viable cones when compared to adjacent individuals comprising a second growth cohort (approximately 170 years old). The old growth trees are clearly still prolific even in advanced age.

Comprehensive Cone Collecting and Seed Banking Program

The "Seed Banking" System

Most native trees used for reforestation are grown from seed. Sufficient quantities of high quality, site-specific seed are therefore needed to restore and sustain plant communities that are increasingly threatened by catastrophic fire, insect and disease outbreaks, human impacts, fragmentation, invasive species, and the effects of climate change. In support of sustainable healthy forests the California Public Resources Code sec. 4681-4695 and Board of Forestry policy direct the Department of Forestry and Fire Protection, CAL FIRE, to provide an adequate, reliable, and continuous supply of site adapted seed of the widest possible diversity and highest quality to promote responsible reforestation and protect the genetic integrity of California's forested landscapes. To that end a comprehensive Forest Tree Seed Bank is maintained to provide the facilities for processing and storage of seed from a maximum number of species and adaptive seed zones. The Department of Forestry and Fire Protection maintains a full collection from all lands as well as provided quality seed storage for private owners who store seed collected from their lands for future use. In addition, private seed banks also store seed for some of their clients according to the same categorization protocols. Finally, the USDA Forest Service maintains its own seed bank.

Cone and seed production are highly variable from year to year. For that reason, developing cone crops must be sufficiently evaluated before collection can be considered. Good seed crops are the exception, so a high degree of advanced planning and cooperation among all stakeholders (USDA Forest Service, state and local agencies, forest companies and private landowners) is necessary to have the requisite reserves of each species from different seed zones and elevation bands in a seed bank for the years in between the bountiful, high quality seed crops.

Vigorous, site adapted seedlings are produced from good quality local seed. Successful seed production requires extensive knowledge of seed development, handling, cleaning, upgrade, and testing and storage procedures. The individual responsible for Seed Bank operations must have highly specialized knowledge of numerous species including: their ranges, adaptations, genetic variability, age to maturity, cone crop periodicity, seed structure and physiology, a variety of maturity indices, dormancy mechanisms, expected seed yield, storage capacity and more. This information is used to determine the seed needs list, the quantity of cones needed to satisfy long-term seed requirements, seed quality standards, crop monitoring systems, and identification of seed collection areas (Table 5.1). Planning in any given year will be based on this knowledge and budget constraints, collection procedures, the need for source certification, and the timing and pace of cone and seed ripening in that collection year. Understanding and monitoring these processes are essential to planning a successful cone collection.

STEP 1 - Determine Long-term Seed Needs

Planning

The first step in the development of any cone and seed collection program is to determine, for each species, the amount of seed required to meet the reforestation and emergency needs over a given planning period. The number of years in a planning period will vary with each species' periodicity and seed storage life expectancy, but is usually a minimum of ten years production plus an emergency reserve for unforeseen events. An adequate emergency reserve is another 50 percent or more above the 10-year production estimate. A simplified calculation is:

Planning period need minus number of trees potentially available from seeds in storage equals seed collection need.

The estimate of seed needed for each species is based on:

- The expected yield (in pounds of clean seed per bushel cones).
- The number of seeds per pound.
- The germination percent.
- The ratio of seedlings to viable seeds.

Table 5.1 Seed Lot Data used to Determine Seed Needs

Species	Avg. No. Cones/Bu	Avg. Lb. Clean Seed /Bu Cone	Avg. Germ %	Avg. Seed/Lb.	Nursery Corr. Factor [a] LAMRC Container Ops	Avg. # Plug Seedlings per Lb. of Seed
Jeffrey pine	35-50	1.2	85	3700	0.72	2664
Ponderosa pine	90-100	1.0	85	9200	0.76	6992
Sugar pine	12-18	1.4	80	1900	0.72	1368
Coulter pine	10-12	0.9	85	1360	0.72	979
Incense cedar	1000s	0.7	65	13600	0.54	7344
White fir	170-200	1.1	70	10200	0.54	5508
Red fir	50-65	0.9	70	4700	0.54	2538
Douglas-fir coastal	900-1000	0.5	85	33400	0.70	23380
Douglas-fir sierra	700-900	0.75	85	27400	0.70	19180
BC Douglas-fir	300-400	0.75	80	4300	0.70	3010
Coast redwood (no)	1000s	0.75	60	92700	0.42	38934
Coast redwood (so)	1000s	0.75	60	86900	0.42	36498

Estimates based on seed lot data from seed processed and grown at the CAL FIRE L. A. Moran Reforestation Center, 1980-2014.

[a] *Nursery correction factors are usually lower for bare root production due to its greater environmental variabilities - Container production is generally a more efficient use of good quality seed.*

Cone Crop Periodicity

Periodicity is the number of years between collectable cone crops. Nature produces a medium to heavy cone crop over a wide area only intermittently, usually once in 3-10 years, or even much longer (Table 5.2). Cone production differs by species, by regional location within a species, from stand to stand, and by individuals in a stand. Good cone crops may occur more frequently on a local basis while some locations regularly fail to produce viable cones. Indeed, failures may occur sporadically across a landscape even in abundant crop years. Furthermore, seed yield, quality, and storability vary considerably by species making procurement of an "adequate supply" an important and complicated consideration. The goal is to collect the maximum amount of high quality seed in good years and store them for the years in between. For example, coastal Douglas-fir trees may have conspicuous cones every three to five years but these are often a combination of insect-riddled and low filled seed cones. An abundant Douglas-fir cone crop with good quality seed in these areas has occurred only three times in the past 50+ years: 1968, 1982 and 1997. In another example, ponderosa pine generally produces a plentiful cone crop at 3 to 10 year intervals in much of its range, however, in the inland coastal area (300 series of zones) ponderosa pine has produced only very light to light crops approximately one in every 10 to 12 years and a good crop has failed to occur in more than 30 years. Cone survey records dating from 1958 to present document generally poor overall crop ratings statewide but show considerable local variation.

Table 5.2 Conifer Reproduction (and Periodicity) Data Chart

Important Reforestation Conifer Species In California	Elev. Range (m)	Max Ht. (m)	Onset of Cone Bearing Age (yrs.) [a]	Reproduction Range (yrs.)	# Years bet. Significant Crops [b]
White fir* *Abies concolor*	1000-3000	55	40	40-400	3-9
Red fir* *A. magnifica*	1400-2700	60	35-45	35-600	3-6
Incense cedar* *Calocedrus decurrens*	50-2960	50	20	20-500	3-6
Coulter pine *Pinus coulteri*	300-2000	25	10-20	10-100	Serotinous
Jeffrey pine* *P. jeffreyi*	500-2900	60	10-20	10-500	2-8
Sugar pine*	150-3000	65	40-80	40-600	3-5

P. lambertiana					
Ponderosa pine* *P. ponderosa*	150-2700	50+	15-20	15-600	4-10
Douglas-fir* *Pseudotsuga menziesii*	700-1800	75-90	20-25	20-500	5-15
Coast redwood* *Sequoia sempervirens*	10-975	84-120	15	15-2200	12-20
Giant sequoia *Sequoiadendron giganteum*	1400-2600	76	20	20-3000	Serotinous
More Narrowly Distributed Conifers in CA					
Pacific silver fir *A. amabilis*	1700-2100	70	20-30	20-500	2-6
Grand fir *A. grandis*	0-50	60	30	30-300	3-5
Sub-alpine fir *A. lasiocarpa*	1700-2200	30	50	50-200	3-5
Port-Orford cedar *Chamaecyparis lawsoniana*	800-1400	60	5-10	5-600	4-5
Whitebark pine *P. albicaulis*	2220-3660	20	20-30	20-700	3-8 [c]
Knobcone pine *P. attenuata*	180-2000	15	10	10-90	Serotinous
Foxtail pine *P. balfouriana*	2100-3700	22	20	20-1500	5-6
Lodgepole pine *P. contorta var. murrayana*	1500-3400	30	15-20	15-600	2-4
Limber pine *P. flexilis*	2200-3350	18	20-40	20-1000	3-6 [c]

Bristlecone pine *P. longaeva*	2600-3600	15	50	50-4000	2-4 [c]
Western white pine *P. monticola*	1370-3170	60	20	20-400	3-7
Bishop pine *P. muricata*	0-400	25	10	10-200	2-3
Monterey pine *P. radiata*	0-300	35	10	10-100	Serotinous
Foothill pine *P. sabiniana*	300-2100	25	25	25-200	2-4
Torrey pine *P. torreyana*	0-175	18	12-18	12-150	Serotinous
Singleleaf piñyon pine *P. monophylla*	1000-2900	12	35	35-800	5-7
Brewer spruce *Picea breweriana*	1150-2700	30-50	20-30	20-900	2-3
Sitka spruce *P. sitchensis*	0-20	70	25-40	25-800	3-4
Big cone Douglas-fir *Pseudotsuga macrocarpa*	275-2400	30	20	20-600	7-10
Western hemlock *Tsuga heterophylla*	10-400	60	20-30	20-500	5-8
Mountain hemlock *Tsuga mertensiana*	1900-2700	30	20-30	20-250	3-5

[a] *In the temperate zone the length of the juvenile period is extremely varied. Reliable and abundant production of viable seed tends to occur at a later age, often after 30 to 80 years.*

[b] *Periodicity - The authors' 60+ years collective experience has been that significant "collectable (economical and operational-size) crops" occur at irregular intervals that often exceed the parameters listed. The periodicity of collectable crops can often be longer at the lower, drier end of the elevation range.*

[c] *P.E. Maloney, personal communication.*

STEP 2 – The Annual Cone Crop Survey

Objectives of the Cone Crop Survey

The annual cone crop survey assesses the potential for collections in each of the specific physiographic and climatic regions of California. The purpose of the cone crop survey is threefold: to forecast the likelihood of successful cone production in the current year; to compare one stand or potential collection area with another; and to collect cone production information for long-term periodicity records. The decision to collect cones in a given year will be based on a systematic crop monitoring process that begins with visual observations of tree crowns in early summer and continues with assessments of the cones and seeds as they begin to mature. The cone crop rating is a numeric method for expressing the size of the potential crop and is based on two factors: 1) the number of well-distributed trees bearing cones in a mature stand, and 2) the relative number of cones in the acceptable portion of the crown on those individual trees. CAL FIRE uses the rating system described on the Cone Crop Survey Form (fig. 5.8). A rating of (4) medium and (5) heavy are generally considered collectable given that seed quality is determined to be acceptable as well.

> CAL FIRE plans to launch a beta version of the Cone Survey Mobile APP in lieu of the standard form below. Statewide rollout is expected in 2019 - 2020.

CALIFORNIA DEPT OF FORESTRY & FIRE PROTECTION
L.A. MORAN REFORESTATION CENTER
CONE CROP SURVEY FORM

Date: *July 10, 2001* **Rating By:** *L Lippitt*

Seed Zone: 523 **Elevation:** 3655’

T: 26N **R:** 10E **Sec:** 30 **Lat:** N40.04.803’ **Long:** W120.53.795’

Stand Observed From: within stand _____ road __xx__

Motor Log: *Crescent Mills- from Hwy 89 take Arlington Rd. approx. 1.75 mi. to a seasonal road on the right accessing Beaty & Assoc. property. Survey is at the landing.*

Comments on Stand Condition: (form, density, access, safety for collection)
Mature mixed conifer stand – some hardwood component, medium density, easy access and safe for climbing. Permission from Beaty for collection access has been arranged.

RATING
(Check number that applies)

Species	PP	JP	SP	DF	CRW	WF	RF	IC	Blk. Oak
1. None					n/a				
2. Very Light								x	
3. Light				X					X
4. Medium	X		X			X			
5. Heavy									

The cone crop rating is based on ocular estimates of cone quantities on dominant and co-dominant trees, 12 inches d.b.h. or greater. Five classes are used as follows:

Rating	Criteria
1. None	No cones on any seed trees.
2. Very Light	Few cones on less than ¼ of the seed trees.
3. Light	Few cones on more than ¼ of the seed trees.
4. Medium	Many cones on ¼ to ½ of the seed trees.
5. Heavy	Many cones on more than ½ of the seed trees.

Figure 5.8 Example Cone Crop Survey Form

Judging “Few” and “Many”

Of particular importance is understanding the different cone production characteristics among the species being assessed, including the variance in number of cones considered abundant and their distribution throughout the crown. A cone crop rating of “few” or “many” is highly subjective and largely dependent on the experience of the surveyor. For example, 80 to 100 cones on a sugar pine or red fir tree would be classed as "many" while the same number on a Douglas-fir would scarcely be noticed. Likewise, several thousand cones may constitute "many" on a Douglas-fir but the same quantity would be rated as "few" on a mature incense cedar. In developing judgment of "few" and "many", attention is confined to the portion of the tree crown expected to bear acceptable cones for that species. In the white pines (sugar and western white) and true firs, cone production is often limited to the top four to five branch whorls. In abundant crop years, cones of ponderosa pine will occur in clusters of three to five or more on the previous year's growth in the upper half of the crown. Abundant small cones on coast redwood or incense cedar will alter the appearance of the tree as the branches literally droop under the weight of a heavy crop (fig. 5.9 to 5.21). For those species with cones found throughout the crown, the highest quality seed cones will be in the top half of the crown on vigorous branches exposed to the sun; seed cones in the lower crown are more likely to be self-pollinated. Additionally, isolated trees (individuals located more than 300 feet from any other of the same species) should be avoided in rating assessments and collections; they are likely selfed, or self-pollinated, and therefore not good genetic material.

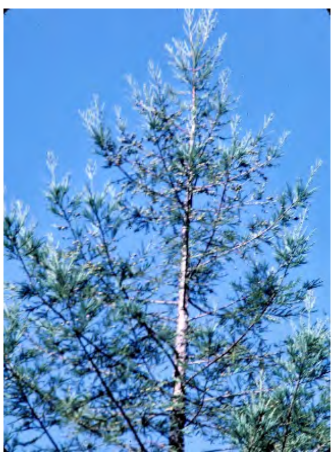

Figure 5.9 (left) Coast redwood – few. **Figure 5.10** (center) Coast redwood – many. **Figure 5.11** (right) Coast redwood – many. *Photo:* Brian Barrett, CAL FIRE



Figure 5.12 (left) Douglas-fir – many. **Figure 5.13** (center) Douglas-fir – many. **Figure** 5.14 (right) Douglas-fir – few.



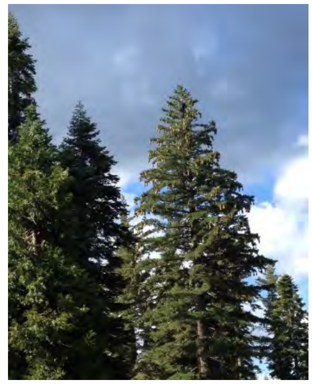
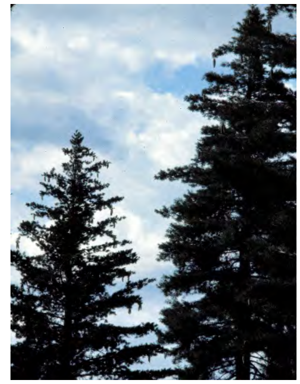

Figure 5.15 (left) White fir –few. **Figure 5.16** (center-left) WF – many. *Photo*: Brook Darley, CAL FIRE. **Figure 5.17** (center-right) Sugar pine – many. *Photo*: Craig Ostergaard, Sierra Pacific Industries. **Figure 5.18** (right) Sugar pine – few (right in photo).


Figure 5.19 (left) Ponderosa pine – few. **Figure 5.20** (center) Ponderosa pine – many. *Photo*: Dave Powell, USDA Forest Service. **Figure 5.21** (right) Sub-alpine fir - few-left, many-right. *Photo*: Canadian Forestry Service, 1989.

The cone crop surveys are completed in early summer when cones are readily visible, usually in June through July depending on geographic region, elevation, and cone year climate conditions. The surveys are done on a ‘stand’ basis within each designated seed zone and across elevation bands within a seed zone. Surveyors observe <u>current</u> year cones on well-distributed, dominant (and rarely co-dominant) seed trees. A seed tree is defined as one of cone bearing age, minimum diameter at breast height greater than 12 inches - often larger depending upon species, with good phenotype, fast growth rate, high vigor, disease-free, straight stem, and small branch size. Well-distributed means seed trees are 100 to 300 feet apart and stands are separated by approximately 600 feet – this large separation is required for wind-pollinated plants.

Surveyors must avoid two common errors when conducting surveys:

- Do not include spent cones (those that have already shed seed).
- Do not sample only roadside trees as they receive more light from all directions and will frequently have a heavier crop (generally not representative of the stand).

Visibility is improved if surveyors keep the sun behind them when viewing cone crops, especially species with small cone size such as Douglas-fir or coast redwood. The survey objective is to collect data from as many sites as possible to ensure a representative cross-section of cone production over a wide area. Surveyors are encouraged to evaluate 20 to 30 or more well-distributed inspection sites from low to high elevation per seed zone. Positive species identification is crucial. Sometimes identification is simple and straightforward because of the uniqueness of a species; Douglas-fir is one example. These cones are highly recognizable due to the characteristic three pronged bracts that overlap each scale. Other species, such as ponderosa and Jeffrey pine, are similar in appearance and have overlapping ranges. Evaluators must look at all species' characteristics to eliminate misidentification of similar-looking trees. In such cases, it is helpful to dissect a few cones and inspect seed structures as well.

Crop Rating

A crop rating is designated for each species present in the sample area and a separate survey form is used at each site evaluated. Based on the results of the cone crop estimates, potential collection areas can be selected for further evaluation. Each stand ultimately considered for collection must have sufficient area and number of acceptable cone bearing trees to meet collection standards and be cost effective. Additional information required on the Cone Crop Survey Form are details of the stand location and condition. It is important to be specific about location – a good motor log (in addition to GPS coordinates) is key to relocating a stand for further evaluation if necessary. The surveyor should also consider and catalog the features of the site when surveying for cone crops and choosing potential collection areas. Examples of useful site characteristics include the local topography and degree of slope, species composition and density, stand age and structure elements, overall stand health, and property ownership, if known.

If an area is selected for collection, then the microclimate features (aspect, slope, soil type and moisture holding capacity, drainage elements, etc.) will be recorded as well. Microclimates exist near bodies of water that moderate the local area. South facing slopes will be warmer and drier than those with a northern aspect. Low lying and shady areas will experience lower overnight temperatures and allow snow and frost to linger. Soils may be rocky or compacted, both of which will affect drainage. All elements of the site are necessary for consideration when making seedling deployment decisions and are included in a report of cone collection.

STEP 3 - Selection of Cone Harvest Trees

Desirable Characteristics

Characteristics such as growth rate and form, branchiness, and pest resistance are highly heritable and vary widely between individuals. Trees with a desirable phenotype may be genetically superior to neighboring trees with less desirable traits and often produce more viable seed. Forest tree selection for cone collection involves choosing parent trees that possess the following desirable characteristics:

- fast growth rate
- full, compact crown indicative of high vigor
- straight stem and minimal taper
- small branch size with horizontal or slightly upward angle
- high needle retention
- strong resistance to attack by insects and disease pathogens
- free of obvious defect such as forking or spiral grain

These genetic differences are important because they are passed on to progeny. Stands containing poorly formed and otherwise inferior trees should be avoided.

Genetic variation is necessary for populations to evolve and undergo adaptive changes in response to changing environmental conditions. The most likely place to collect seed with the genetic combinations that are best suited for long-term survival on a given site is on or very near the site itself. Decades of research has demonstrated that the use of non-local genotypes can result in immediate or delayed mortality, poor vigor and reduced fertility (Guinon 1992). In addition, non-local seed can introduce inferior or maladapted genotypes into the ecosystem. Failures from improper seed source may not become apparent for many years because of the slow growing nature of trees.

Broad or Narrow Genetic Base

The ability to adapt to different environmental conditions varies considerably among California tree species. Some species have more adaptive traits and are referred to as "generalists". Genetic generalists are varieties that perform well in a broad range of environments. Incense cedar, *Calocedrus decurrens* and western white pine, *P. monticola* are examples of species that can tolerate a wide range of elevational and climatic gradients and may be better able to adapt to a variety of environmental stresses. Ponderosa pine, *P. ponderosa* is one of the most widely distributed conifers in California and is characteristically present in the mixed conifer type from approximately 500 feet near coastal and foothill environments to more than 9,000 feet on the west slope of the Sierra Nevada. Ponderosa pine succeeds in a variety of soils, exposures and environments and is considered "intermediate" in adaptive traits. In broad terms, generalists and intermediates have more genetic diversity and can move farther in both seed zone and elevation than other species.

Douglas-fir, *Pseudotsuga menziesii* is known as a genetic or climatic "specialist" in adaptive traits. Specialists show strong genetic variances over small geographic and climate ranges. Douglas-fir has an extensive latitudinal range in the Pacific Northwest and is broadly distributed in California, but movement out of its local range typically causes decline in productivity or even death. The coastal and Sierran populations within California are morphologically and ecologically dissimilar and are not recommended as interchangeable. Measurable genetic differences can be found in Douglas-fir populations separated by just 200 m (656 feet) of elevational change and in response to temperature extremes, number of frost days and drought stress (Rehfeldt et al. 2014). Another specialist is bigcone Douglas-fir, *P. macrocarpa*; restricted to fragments of the Southern California forested region in canyons, canyon bottoms, and mostly northern and eastern slopes. Its endemic status in California and limited range of favorable environmental conditions of temperature, soil, and precipitation mark bigcone Douglas-fir as potentially maladapted to future projected environmental conditions. Adverse effects due to climate change are expected to have a greater impact on specialists and other marginal populations such as regional endemics, those at the trailing edge of range and high elevation alpine species, making them more vulnerable to extirpation if conditions change too rapidly.

Inbreeding

Within a stand, it is highly likely that many individuals are related. Conifers are wind-pollinated and therefore require a larger separation between seed trees than other plants to promote cross pollination; 200 to 300 feet apart is recommended. Selfing and close relative mating can have significant negative impacts on seed crops and tree populations produced from open-pollinated seed. Inbreeding results in loss of seed yield, lower germination rates, poor storability, poor seedling vigor, and higher mortality rates (Table 5.3).

Table 5.3 Inbreeding in Pinaceae

Trait	Loss Due to Inbreeding
Yield	-50%
Seed Germ %	-12%
Height Growth	-12%
Mortality	+1.3 times

Source: Franklin, 1970

It is essential to choose collection candidates with care. The best approach to avoid inbreeding and decreased vigor of progeny is to collect from a number of widely spaced trees in a stand, collect an equal number of cones from each, and from a number of different stands within the same elevation band of a seed zone. A stand is considered different when separated by a minimum of 600 feet from an adjacent collection area. With seed from many stands collections are more likely to include individuals adapted to local variations such as cold or drought hardiness, vegetative bud phenology, disease resistance, soil conditions, etc. In addition, collection priority for operational size collections should be given to stands and individuals at the center of the range. These are generally more broadly adapted and can be moved farther than material at the margins of a species range.

Location to location variation still exists, even among individuals and stands in the same elevation band. This is especially important on harsh sites or in regions that experience severe climate events. In this way the environmental, or climatic, distance between seed source and planting site is more important than geographic distance when considering a good match for deployment. Notably, collections from fragmented or threatened populations, or individuals at the trailing edge of the range where frequency is lower (areas typically excluded for bulk collections) should be considered a priority in future for gene conservation. These types of very specific collections should remain separate from operational-sized collections.

Selection of trees for collection in natural stands represents an opportunity for improving the overall health of the forest. While collection candidates are compared with adjacent trees for phenotypic characteristics, tree health or lack thereof is also critical to the success of collection efforts. Parent trees must show resistance to disease, a strongly inherited trait. Trees with mistletoe or other disease may have a heavy crop, but it is important to avoid collecting from these individuals or from stands containing diseased trees. Removal of diseased trees and general thinning is recommended to promote healthier and more resilient stands while also stimulating larger cone crops by reducing competition for light, nutrients and growing space.

Summary - Cone Harvest Tree Selection Standards (General Collections)

- Collect only from trees with desirable phenotype in stands with a high proportion of desirable trees – pollen from trees with poor form can affect the quality of progeny.
- Do not harvest cones in areas that had a poor pollen crop (as evidenced by observing the number of trees in the vicinity with abundant spent male cones present or on the ground).
- Collect only in years of moderate to heavy cone and seed production throughout most of the seed zone. Moderate means the majority of dominants and approximately 50 percent of the co-dominants are producing cones.

- Maximize diversity by maximizing the number of unrelated individuals represented.
- Avoid seed cones from trees with low filled seed counts (below 50% filled) that are not otherwise attributable to damaging agents such as frost or insects.
- Avoid collecting cones in the lower third of the live crown – there is an increased probability of self-pollination below mid-crown.
- Avoid isolated trees and small isolated stands – these are usually inadequately pollinated.
- Avoid stands or areas that have been selectively logged.

The goal is to collect seed lots that represent the maximum number of unrelated female parents – A minimum of 33-50 individuals is required for a 100 bushel size lot, ideally two bushels maximum per tree. Each stand collected from shall be separated by at least 600 feet.

Note - It is typical for some individuals in a population to produce more seed than others. Do not skew bulk collections by collecting more cones from “loaded” trees. An equal amount from each is necessary to maintain equal representation of donor genes.

STEP 4 – Cone Collection

The objective of any cone harvest is to collect the assigned quantity of high quality cones during the appropriate window of opportunity in a safe and cost efficient manner. Important factors to consider include:

- target species availability
- crop size
- collection timing
- collection site certification
- cone handling and transportation
- cost

Collections are inherently more efficient and successful when crops are bountiful and filled seed numbers are high. Yearly variation in cone production, collection timing, and seed quality can be very high so early determination of quality or lack thereof can prevent expensive failures.

Seed Maturity

Even with an abundant cone crop it is important to examine cones and seeds for quality and progress toward maturity. Seed maturity is vitally important! The relationship between seed maturity and germination capacity and yield is well established. Seed maturity has been defined as the stage at which seeds are capable of germination and successful storage (Edwards 1981). Seeds that are collected too early may germinate but they will be of low vigor and may perish in storage.

Mature seeds have greater vigor and establishment potential, higher yield, and increased storage capability. Seed maturity is generally associated with dispersal. The best time to collect cones is when they begin to open on the tree, but that is rarely practical with operational size collections. Instead, collectors must know how far in advance cones may be harvested without compromising seed quality. This may be a matter of days or up to three weeks in advance of natural seed shed depending on the species being collected and anticipated weather conditions. Cutting a sample of cones longitudinally and slicing the extracted seed is necessary for an accurate assessment.

Note: Specific gravity tests in the field had long been used to estimate collection start dates, but cone and seed cutting tests have become the preferred method because of increased reliability and ease of use in the field.

Evaluating the cone crop involves closely observing common indicators of ripeness including cone color and condition, seat coat and wing color and condition, evidence of insect or fungal damage, and internal tissue color, texture and condition. These physical and physiological indices are reasonably dependable but can be subjective and differences vary widely among species, between cones on the same tree, between individuals in a stand, and populations across the landscape. The reliability of these assessments is dependent on the experience of the observer.

Major Ripeness Indicators

As cones ripen, there is a gradual but obvious reduction in moisture content – they will "feel" lighter. This moisture loss is accompanied by changes in cone color and texture. Cone color varies by species but, in general, cone exteriors change from a vegetative green to some shade of yellow-green or golden to brown. There will be a slight flexing of the scale margins. Every effort should be made to collect when cones and seeds are fully mature. However "after-ripening", a method infrequently used to improve cone and seed maturity when collections are premature, may be possible for particularly valuable collections (of DF, SP, or true fir) under strictly controlled conditions of cool temperature (10^{o}C), relative humidity, and sufficiently rapid air movement.

A representative sample is a must in order to accurately estimate the quantity of sound seed available and the degree of maturity attained – 2 to 3 cones from the top half of the crown from several unrelated trees in a stand is ideal. The sample cones are cut lengthwise through the center core and the exposed seeds are counted on one cut face. The seed minimum (average) per cut face varies by species but, in general, if 50 percent or more of the cut seed is empty or damaged then a collection is not considered worthwhile (fig.

5.22). The percentage of desirable seeds required increases to 75 percent for pines (fig. 5.23, 5.24). The seeds at the tip and base end of the cone are not considered in this count because, for most species, these areas likely contain a high percentage of undeveloped seeds (Table 5.4).

Figure 5.22 (left) Coast redwood - >75% filled. *Photo*: Bill Morrison, Soper-Wheeler Company. **Figure 5.23** (center) Sugar pine - poor filled seed count. **Figure 5.24** (right) Sugar pine – >75% filled.

Conifer seeds have three main components: the seed coat, embryo, and megagametophyte. Seed coat morphology among trees of different species is quite variable in color, shape, size, texture and the presence or absence of seed wings and resin vesicles. Even seeds from different trees of the same species will show great variability in seed color, shape, and size. As they mature:

- The seeds become easier to separate from the scale.
- The seed coat will begin to harden.
- The seed coat color changes from pale green, orange, magenta or tan-gold to golden, dark and/or mottled brown.
- The seed wing will darken, begin to dry and separate more easily from the scale, approach a golden to medium brown color, and feel somewhat brittle, similar to "parchment paper", when exposed to air.

Table 5.4 Major Ripeness Indicators

Selected California Conifers	Min. sound seeds per cut face [a]	Cone color and condition (not the best indicator of ripeness) [b]	Seed coat and wing color and condition	Embryo and Megagametophyte Color, texture and condition	Favorable collection period (wide geo-elevational variability) [c]
White fir *Abies concolor*	50%	Greenish-yellow to golden, may have a greyish or purplish tinge	Cream or tan color and soft, contains more resin vesicles than RF, loosely	Embryo occupies 90-100% of the cavity, yellow in color, cotyledons	True fir cones disintegrate fairly quickly

		at ends; Cone scales will become slightly pliable	attached to scale; wing is golden brown with magenta or golden margins and slightly translucent (if seed coats and wing all purplish still, it's too early), wings feel papery	well-developed; mega will appear whitish, fleshy and firm though may be somewhat oily in appearance	upon maturation, so must be collected slightly prematurely. Late Aug-October
Red fir *A. magnifica*	50%	Greenish-brown to russet brown with reddish or greyish tinge; cone scales will change from rigid to pliable before scales dehisce	Coat reddish-brown and thicker than WF, loosely attached to scale; Shasta RF have visible bracts on scale exterior; wing reddish-brown with magenta margin and papery	Embryo occupies 90-100% of the cavity, yellow in color (the radicle end is encased by a root cap); mega is fleshy and firm, somewhat oily in appearance	September through October
Incense cedar *Calocedrus decurrens*	2	Yellowish-green to golden tinged with shades of brown. Cone tip will flex slightly	Thin papery seed coat ripens to light tan color; has 2 persistent wings that must remain intact (to avert damage to embryo)	Embryo is bright yellow (may have pinkish radicle end) and 90% extended; mega is firm and oily in appearance	Mid-August to October Very perishable – be alert to overheating
Jeffrey pine *P. jeffreyi*	10	Greenish-purple to yellowish-brown or dk. purple to lighter purplish-brown, scales begin to flex	Coat pale brown color, hardened, smooth evenly brown on top, coarser on scale side; wing light tan to brown & brittle, adheres to seed coat	Embryo is creamy white and 90% length of cavity; mega is whitish color, opaque, firm and nutlike	Early September through October
Sugar pine *P. lambertiana*	12-15	Yellow-green to light brown; cone scales become less rigid and begin to flex	Seed coat is dark brown (orange & mottled orange-brown is pre-ripe color); wing is dark brown, thin and papery	Embryo is 90% length of cavity, yellow color; mega is creamy white, opaque and firm, not milky	Mid-August through October
Ponderosa pine *P. ponderosa, var. ponderosa*	8-10	Pale yellow-green to light brown-green to lustrous yellow-brown, scales begin to flex	Pale brown to grey-brown and usually mottled on scale side, hardened; wing golden to tan, brittle, adheres to seed coat	Embryo is 90% length, pale yellow color; mega is whitish color, opaque, firm & nutlike	Early August through September
Douglas-fir *Pseudotsuga menziesii var. menziesii*	5-6	Pale yellowish-green to golden brown color, 3-lobed bracts will	Golden brown to dk. brown, shiny and darker on one side, hardened; wing lt.	Embryo occupies 90-100% of the cavity, pale yellow color; mega is	Earliest ripening cone at lowest

		turn golden brown first (but may brown prematurely due to insect activity as well)	brown to tan, easily detaches from scale. Coastal seeds are longer with pointed tips; interior generally rounder tips and more triangular-shaped	whitish color, full, opaque and firm	elevations late July-August. Most seeds released by October
Coast redwood *Sequoia sempervirens*	3-4	Greenish-yellow to golden brown; cone scales separate slightly	Reddish-golden to red-brown (should not be green tinged). Wing is slightly lighter color and is part of the seed coat	Embryo and megagametophyte are barely indistinguishable without magnification, but whitish color and firm	Early October to November

[a] *For pine, DF, and RW – place cone on a hard surface and cut lengthwise from stem to tip through the center axis exposing the cut seeds, count the number of filled seeds on one half only. For true fir – cut cone lengthwise from stem to tip and parallel to the core but offset by ~¼ to ½ inch. The seed count is measured as the percent of exposed seeds that are sound. For incense cedar – cut cone through the bottom third widthwise – observe from one to four seeds per cone (rarely up to six).*

[b] *Determining maturity by exterior cone color can be very subjective; color varies by individual, population, site and weather.*

[c] *Physical characteristics vary with location and elevation. Maturity may differ by more than one month between low and high elevation sites. Seed dispersal is greatly influenced by local weather patterns. If unusually warm or drying winds, seeds of most conifers will disperse in a matter of days.*

Embryo and Megagametophyte

The seed cutting test is a seed anatomy test. It reveals the proportion of filled (presumably viable) seed and degree of maturity. A sample of seeds are bisected on the longest axis and thinnest dimension to visually examine the embryo condition and length; the cut must be precisely through the center because an improper cut will not show true embryo elongation. The number of seeds sampled varies by the precision required and whether it is a field test (10 to 20 seeds) or a post-harvest examination in the Seed Lab (100 seeds per lot). As it matures, the embryo loses moisture and differentiates from the megagametophyte, turns creamy to pale yellow in color and elongates to fill the embryonic cavity; embryos nearing acceptable maturity will fill approximately 90% of this cavity (fig. 5.25). The cotyledons develop fully and become visible at the rounded (chalazal) end and the hypocotyl and radicle extend toward the pointed (micropylar) end of the seed when fully elongated. A thin suspensor connecting the radicle to the micropylar end may still be visible if the embryo is underdeveloped (fig. 5.26). The color, texture and general appearance of the megagametophyte varies with the moisture content of the tissue as well. When immature, the megagametophyte appears gelatinous or milky (fig. 5.27). As it matures the color and texture changes; moisture is lost and the megagametophyte becomes opaque, firm and nutlike as it differentiates from the embryo. If cut while still immature, the megagametophyte will shrink away from the seed coat if it is left exposed to sunlight or air. In true fir and incense cedar the megametophyte normally appears somewhat oily because of the many resin vesicles within the seed coat. Damaged megagametophyte tissue will appear grey or yellowish in color and may have a rubbery or chalky texture.


Figure 5.25 (left) *P. menziesii* seed **-** mature appearance with embryo fully extended (left).
Figure 5.26 (right) *P. menziesii* seed with embryo <50% and suspensor still clearly visible.
Photos: B. C. Ministry of Forests, 1989.

Figure 5.27 Immature *P. macrocarpa* seed: seed coat color pale, megagametophyte quite moist. *Photo:* Arnaldo Ferreira, USDA Forest Service, 2014.

Evidence of Insects

The presence of insects in cones is often externally apparent by one or all of the following: premature browning or flexing as a whole or in patches, small holes caused by boring, excessive pitch exudation, presence of frass, and areas of disfigurement (fig. 5.28, 5.29). Insect damage will result in lower seed counts and a decrease in the number of seeds that can be extracted from the damaged cones.

Figure 5.28 (left) Localized scale damage (darkened areas) on *P. menziesii* by *Contarinia oregonensis*. **Figure 5.29** (right) *P. ponderosa* damaged by *Dioryctria spp*. Cone scales patchy in color and frass grains at stem end. *Photo*: USDA Forest Service – Ogden, Bugwood.org.

Problems That Result from Collecting Immature or Insect Damaged Cones:

Many problems can be encountered with immature and insect damaged cones and seeds. Immature seeds are harder to extract and process because the cones tend to dry too rapidly once they are separated from the tree and the scales will case harden in a partially flexed position. This traps the seeds inside the cone and reduces yield. Immature seeds have reduced germinative capacity and they are slower to germinate. Germinants of immature seeds are less robust and produce seedlings with decreased vigor. Immature seeds are more susceptible to fungal attack and diseases, and they tend to have more abnormalities which leads to eventual death. When seeds are collected too soon they are less viable and will decline in storage at a much faster rate than seeds that are fully mature when collected.

Figure 5.30 (left) Excessive debris and pitch in this seed lot of *P. lambertiana* makes processing and seed upgrade difficult. **Figure 5.31** (right) *P. menziesii* cone heavily burrowed by *Choristonuera occidentalis*, western spruce budworm. Photo: Canadian Forestry Service, July 1980.

Insect damaged cones are harder to extract and process because they often are contaminated with frass and pitch exudation which fuses the seeds and scales, preventing the seeds from falling freely during extraction (fig. 5.30). In addition, insect activity often causes deformation of cones; the affected areas do not flex and the seeds are trapped (fig. 5.31). In the above situations there will be a significant decline in seed yield. During upgrade, seeds with an insect larvae inside may be more difficult to separate from filled seeds because they often have the same specific gravity – the result is a seed lot with fewer germinable seeds. Damaged cone fragments, seeds, frass and insects contaminate the seed lot and the equipment being used and make seed cleaning far more challenging. These seed lots must often be consigned to the end of the processing cycle, after the healthier lots are completed, because of the extra time and effort that they require.

Collection Timing is Critical

As noted, cones and seeds must be physiologically mature at the time of collection or seed viability and vigor will be unacceptable. In California, the majority of forest tree seeds reach physiological maturity in late summer and early fall about one to two weeks before natural seed fall. The actual timing of the collection and the length of the harvest period in a given season will depend on the species, area of the state, elevation of the site, and local weather conditions. Moisture, temperature and altitude play an important role in local ripening. For example, a warm, dry summer or sudden drying wind can cause early cone opening and seed release. Conversely, a late spring, cool summer or wet fall can delay cone ripening and lengthen the collection period. For the most part, cones ripen first at lower elevations and on west and south facing slopes and later at higher elevations and on eastern and northern exposures (Schubert, Adams 1971). Not all cones in a stand, or on a single tree, ripen at exactly the same time so it is best to wait until the majority are ripe than to begin too soon. However, collecting too late may be detrimental because seeds may be lost to seed shed, predation by animals or insects, or to seed deterioration (Karrfalt 2008).

Species with serotinous cones are an exception to the fall maturity and one to two-plus week collection window. The collection period for Coulter, Torrey, foothill and knobcone pines may instead be several months after fall maturity because resins prevent the scales from opening immediately after ripening. Collection of these species may be conveniently scheduled after other time-sensitive collections are complete.

Serotiny is an ecological adaptation in conifers that prevents immediate seed dispersal upon maturation. The cones remain closed on the parent tree for a year or more after the seeds have matured. In some species of pine and cypress, serotiny is more severe and seed release usually occurs in response to an environmental trigger such as fire or after treatment artificially in a cone kiln at a processing facility. Cones that exhibit this type of serotiny include knobcone pine, Monterey pine, Bishop pine, Coulter pine from the central coast (seed zones in the 100 series) and the cypresses.

Giant sequoia, though not truly serotinous, is another interesting exception to the fall-collect pattern. Giant sequoia cones are persistent; they remain in the crown for many years past peak maturity and intermittent seed fall. Mature older cones (>6 years old – yellowish-green with brown stem/peduncle) may be collected at any time of the year but may have approximately ten percent fewer viable seeds depending on the age and condition of the cone. The very old cones (grey, usually lichen-covered) commonly contain very few viable seeds, having intermittently flexed their scales and released seeds during warm, dry periods over many years.

Fresh (three-year) cones are physiologically and morphologically mature in the fall thirteen months after fertilization and these cones open readily upon detachment and drying. However, first year cones (immature, just-fertilized females) may also attain nearly full size in this same time period (Sept to Oct) and have often been mistaken for mature cones (fig. 5.32). In one study on the University of California Whitaker's Forest adjacent to Kings Canyon National Park, researchers are looking at differences in seed yield and germination capacity between cones of different ages, where cone age is related to cone color and morphology (fig. 5.33, 5.34). The goal is to identify, for collection purposes, the ideal "collectable" cone. (Ken Somers, Center for Forestry, University of California, Berkeley, ongoing research, 2017).

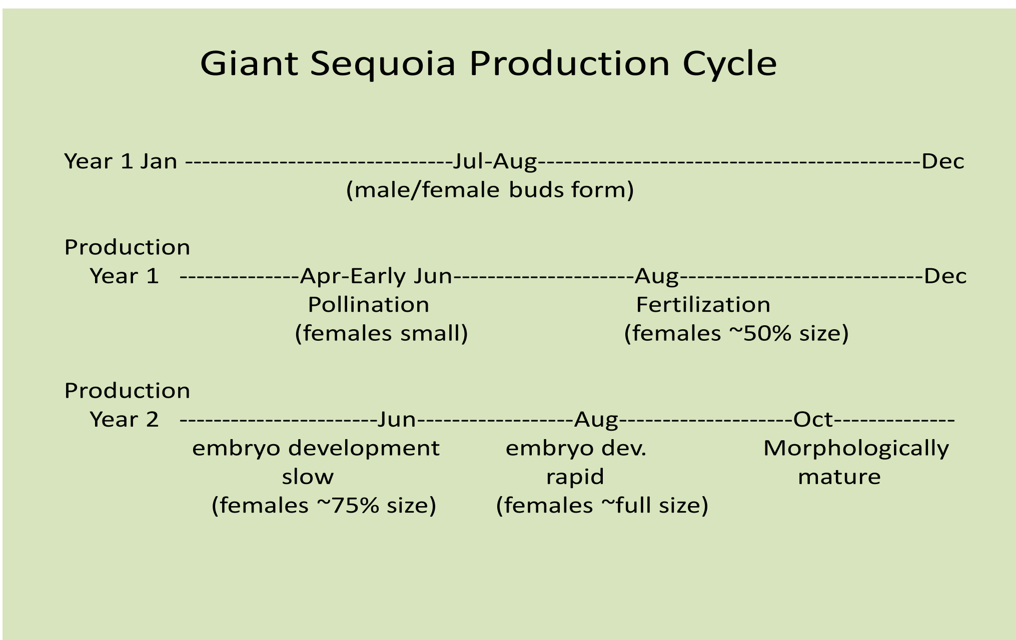

Figure 5.32 Giant Sequoia Production Cycle.


Figure 5.33 (left) GS Tree #274 - June 2015, just pollinated female conelets (top), mature cone (bottom center). **Figure 5.34** (right) GS Tree #274 – June 2016, now-fertilized females (top). They must continue development before attaining full embryo maturity in Sept - Oct 2016. Same mature cone (mid-center). Photos: Ken Somers, University of California, Berkeley.

Collectors must be alert to sometimes subtle color differences between first year cones and those that are fully mature when fall collecting giant sequoia to avoid collecting unripe cones. Making this distinction is easiest in a late spring or early summer collection (late May to June) of giant sequoia cones that fully ripened the preceding fall when color and size differences between mature and immature cones are more conspicuous. Early findings show that seeds from delay-collected fall ripened cones consistently show higher germinative capacity and increased seed yield when compared to fall collected giant sequoia which may include unripe cones.

Cone and Seed Losses

Cones and seeds may fail, post development, for a variety of reasons. In a cutting test, the two most easily recognized causes for the failure of a seed to germinate are lack of a properly mature embryo and complete deterioration of all seed contents (Kolotelo 1997). Empty seeds are common among many conifers because they may still develop a seed coat and megagametophyte without fertilization. One example is *Abies* seed. Without a fertilized embryo the megagametophyte of an *Abies* seed will eventually deteriorate, leaving a seed coat that is woody and difficult to cut during sampling. Conversely, an unfertilized pine seed does not develop megagametophyte, therefore it will have a lower specific gravity and be easily detected by crushing during assessment, or later removed by air separation during upgrade.

Conifer seeds with partially or completely deteriorated contents (dead-filled seed) may have been attacked by pathogenic fungi or may be the result of insect damage. Several species of fungi are known to cause damage to conifer seed and seedlings. Particularly harmful are those belonging to the genus *Fusarium*, which causes pre- and post-emergence damping-off. The affected embryo and megagametophyte may still be visible but with obvious discoloration, may appear as a solid mass, or may be missing entirely. These dead-filled seeds often have the same specific gravity as healthy, filled seeds and are harder to separate during processing.

Seeds with resin vesicles (true fir, incense cedar) may be damaged by overheating and rough-handling at any stage post-harvest. Damage to resin vesicles will result in decreased germination or death of the seed. Seeds with damaged resin vesicles may emit a foul odor, have a tacky feel, and the seed coat may be discolored. It is important to keep freshly harvested cones out of direct sunlight and limit movement and potential damage to sensitive seeds during collection handling and transport. Do not stack the cone sacks in piles and do not throw them onto or off the truck while loading or unloading.

Cone and seed insects are the most significant cause of seed losses, post cone development stage, especially in years of light seed production. Coneworms, midges, seed chalcids and maggots may easily destroy 50 percent or more to nearly all of a seed crop in some years. An especially damaging insect affecting a majority of high value tree species is *Dioryctria*, a coneworm that bores through cones and seeds, feeding indiscriminately throughout the season. Coneworm caterpillars continue to cause damage in cones awaiting processing until they pupate later in the fall. If populations are especially high, it may be necessary to expedite seed extraction from affected seed lots and get the seed into coolers to slow further damage. Another harmful insect that attacks Douglas-fir, true fir, and pine species is *Megastigmus*, a seed chalcid. A single larva consumes the entire contents within each affected seed and remains undetected inside until a cutting test or x-ray radiograph reveals its presence. Some insect species' feeding or tunneling activities cause extensive seed yield losses as well by causing distortion to the cones or by fusing seeds to the scales, making seed extraction efforts difficult to impossible (See Table 5.5). The tendency of natural stands to produce large crops in some years and none for several years (periodicity) has led to biological strategies in which insect populations survive low cone production years by greatly reducing their numbers and then re-emerging in large numbers when cone production resumes, often destroying the entire cone crop (Kolotelo 2001).

Table 5.5 Significant Cone and Seed Insects

Significant Cone & Seed Insects								
	Host Conifer							
Insect	DF	WF/RF	PP	JP	SP	IC	Larva Color	Type & Extent of Damage
Cone Beetle *Conopthorus*			x	x	x		White, C-shape, lt. brown head	Bores into cone at stalk or base, killing cone-may see pitch globule here. Cones will be underdeveloped or brown & shriveled. Moderately common in some years – cones are not collectable.
Cone Moth *Barbara, Eucosma*	x	x	x	x	x		White w/ dark head	Burrows w/in cone. Cones are pitchy, brown & deformed. May see pitch & frass on cone exterior. Can see damage by mid-summer – extensive destruction of seed and scales. One larva can destroy 60% of seed in a cone, damage may be 50%+ of the crop.
Cone Worm *Dioryctria*	x	x	x	x			Amber brown to dark red-brown	Bores thru cone scales and seeds – feeds indiscriminately. May see round holes & coarse frass. Seeds may not flex in area of damage; cones badly distorted. May destroy most of a poor crop and >50% of a good crop.
Cone Scale Midge *Contarinia, Asynapta*	x	x					Small, bright orange to red	Deforms cone and fuses seed to scale, forming swollen galls. Greatly impedes to red extraction of seed from cones.
Seed Chalcids *Megastigmus*	x	x	x	x			Small, white, curved and footless	No external evidence of damage. One larva develops per seed and consumes all seed contents. The larva remains in seed or may see round exit hole where adult emerged. Damage is complete by harvest. A major pest on DF and PP.
Seed Moth *Cydia (Laspeyresia)*		x	x	x			White w/ black head	Consumes seed moving from one seed to another leaving each filled with frass, then bores into axis. Usually no external evidence of damage. Once in axis, no further seed damage is expected. May destroy 30%+ of crop.
Seed Cone Maggot *Earomyia, Hylemya*		x					White w/ black mouth hooks	Consumes seed & moves into axis. No external evidence of activity but will see holes on seed coat. Larva exit in late summer – damage is over by harvest. Abundant in true firs.
IC Tip Moth *Argyresthia*						x	Small, green w/red dorsal bands	Mines cones and seed. May destroy almost entire crop.
West. Spruce Budworm *Choristoneura*	x	x					Brownish head, body, blackish head capsule	Feeds on male and female flowers and bores into developing cones. May cause significant decline in seed production.
West. Conifer Seed Bug *Leptoglossus*	x		x	x	x	x	Adult insect w/orange & black bands on abdomen	Pierces seed scale & sucks out immature seed content, collapsing the megagametophyte and rendering it gray-brown; or may leave hard seed coat intact but the tissue inside becomes withered, off-color and spongy.

DF – Douglas-fir; WF – white fir; RF – red fir; PP – ponderosa pine; JP – Jeffrey pine; SP – sugar pine; IC – incense cedar.

Methods of Collection

Figure 5.35 Climber ascending a giant sequoia.

There are several different methods for accessing tree crowns for ripened cones on selected trees. There are advantages and disadvantages for each method listed in this section but the safety of the climber and the tree must be considered first and foremost. In California, collections in wild stands are usually done by trained individuals who free climb selected standing trees; gaining access to sturdy branches in the lower crown via rigging ropes or occasionally using special ladders. Entry into the lower crown of taller trees may be accomplished by firing rope up to 120 feet with a (Big Shot) sling or up to 200 feet with a crossbow to the first supporting branch and, using appropriate gear, rigging the ascent to the top of the crown (fig. 5.35). The climber then ties onto the bole for support and accesses cones at the ends of branches with pole pruners or special hook devices designed to pull the ends of the branch within easy reach for clipping.

Climbing spurs are infrequently used but should not be used on especially valuable trees or species with stems that could be easily damaged such as five-needle pines and white fir. Free climbing is practical in open grown stands of trees up to 100 feet tall. Branches must be well spaced and large enough to support the climber. Tools are hoisted up after the climber is safely secured in the tree crown. It is best to start at the top of the crown where the crop is normally heaviest and work down to the lowest acceptable collecting portion of the tree, usually mid-crown. Cones are bagged in the tree and lowered to the ground, or branch ends with cones attached may be clipped and dropped onto tarps when vegetation or other means of providing a cushioned landing is available. Sugar pine and true fir cones are known to suffer serious impact damage (shattering) when dropped to the ground, therefore should be bagged in the tree and lowered to the ground without exception (Lippitt, Griffis, unpublished data, L.A. Moran Reforestation Center 1986).

In orchard and plantation applications where tree spacing and terrain allows, truck-mounted ladders or hydraulic lifts are suitable to access tree crowns up to the designated height determined by the machinery in use. Impediments to this method are the high cost, availability and efficiency of the equipment being used, tree crown height limitations, and the enhanced organization of crew required on the ground.

Helicopter collections using an aerial cone rake may be practical in coastal areas, on especially steep terrain, and other limited access areas where large cone crops are concentrated in the top whorls of narrow, conical crowns. This method has been very successful for coast redwood collections in California. Helicopter collections can be more economical when a large quantity of high quality cones are available but they are generally high cost, require highly trained pilots, are often hampered by unfavorable weather conditions, and pose a greater risk of damage to the trees.

Collecting from felled trees during active harvesting operations can make access to cones easier but this method offers many disadvantages. Timing is most critical: if falling occurs before the cones are properly mature, ripening will cease and the cones and seeds will dry out; if collected too late, the cones may open and seed may be lost. There is also a high risk of fungal contamination to cones through ground contact, a greater percentage of cone and seed losses due to impact damage and incomplete recovery, and high potential for injury to workers.

Seed Lot Identification

The importance of maintaining accurate seed lot identification cannot be overstated. The goal of conscientious labeling and record-keeping is to provide the most comprehensive seed collection and site specifications to forest managers so they have the tools they need to make sound deployment decisions. The collection supervisor (Registered Professional Forester or Certified Silviculturist) approving the cone collection shall record the species, location information including latitude, longitude and county of origin, date of collection, number of bushels collected, genetic base, and a complete profile of the collection site on a Report of Cone Collection. One example of a standard form for tracking seed lot archives is the FM-44 used by CAL FIRE. The seed lot data is recorded on this form during a mandatory site visit during the collection to verify the details of the collection. The FM-44 is a permanent record that includes a progressive numbering system identifying a given seed lot from collection through to nursery production (fig. 5.36). During collections, the seed lot number is written on each collection tag along with the species, seed zone and elevation, *latitude/longitude and/or township, range and section(s), and the date(s) of collection. Two seed lot tags are mandatory per sack; one inside, and one attached on the outside with a tie at the top – the inside tag is insurance against seed lot identity loss should the outside tag become detached. It is important to specify all information requested on the tags legibly with a permanent marker or waterproof ink to prevent fading or damage during inclement weather and to avoid seed lot confusion.

*Note: For decades, Township, Range, Section(s) was universally required to record location information but in recent years GPS coordinates have become standard. Computer programs easily convert one format to the other.

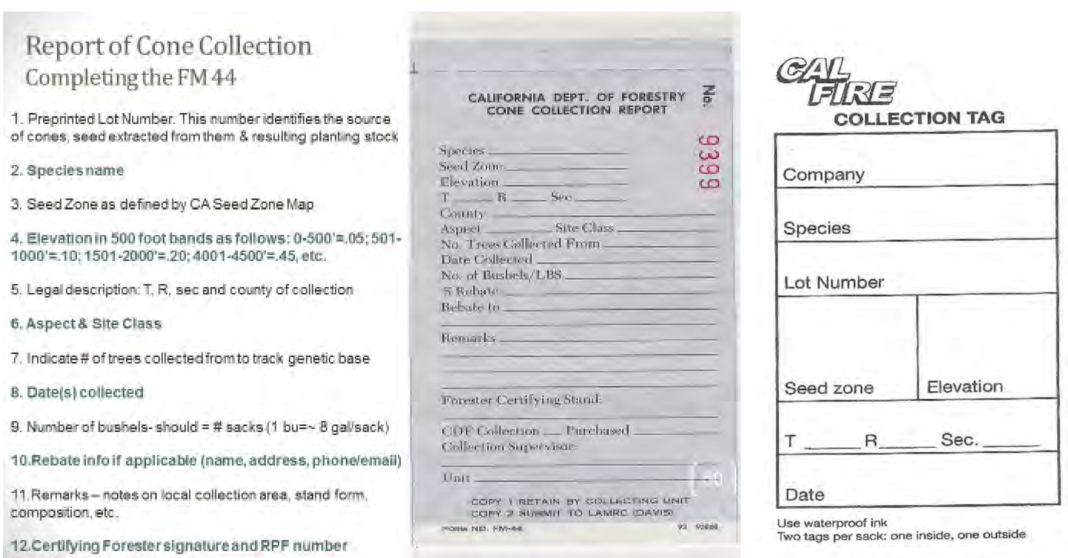

Figure 5.36 Samples of Agency collection documentation forms, FM-44 (left), Collection Tag (right).

Interim Handling and Storage

Cones and seeds are highly perishable. Correct field handling at this stage has long term effects on seed viability, seed longevity and seedling vigor. <u>Adequate ventilation and free air flow are the most important</u>

criteria. Even mature cones contain water – they expand as they dry and generate heat. Heat encourages mold and the webbing formed by mold results in direct damage to the seeds and hinders seed extraction efforts. Mold on the seed surface can compromise germination and subsequent storage life. Collections of true fir and incense cedar are especially prone to such damage because of their characteristically high moisture content at maturity.

Collection sacks should be constructed with strong mesh fabric, or burlap sacks may be used if not too heavy or woven too loosely – they must allow free air flow but disallow seed loss through the open weave. One bushel of cones per two-bushel sack is ideal, filling only to the half-way mark and fastened at the top, to allow ample room for cone expansion. Overfilled sacks damage seed; cones are more prone to mold or compression-hardened scales when they remain wet longer due to over-crowding. Debris in cone sacks such as needles, twigs, bark, and unacceptable cones should be avoided. Such debris are known to cause abrasion, bruising and tissue damage to seeds and result in decreased seed viability and reduced yield. Inclusion of spent cones may cause contamination of the seed lot with fungal spores.

In the field, interim cone storage racks and portable fans allow for unrestricted air movement. If racks are unavailable, a building with open sides may provide good cross ventilation. The sacks must lie free from each other in the shade, turned at regular intervals (daily if not on racks, every other day otherwise) to facilitate even curing and avoid case-hardening, and never left in piles on the ground. Avoid heating by direct sunlight and additional moisture from rain. Wet cones should be spread out to surface dry and re-sacked as soon as possible into dry sacks. Cone sacks should not be covered with plastic while interim stored or during transport. To minimize damage to cones and seeds from overheating, the cones should be transported to the processing facility as soon as possible and must not be left in a truck overnight. For best results, cone delivery within twenty four hours of collecting is highly recommended. Open-sided trucks or trailers with netting to stabilize the load and refrigerated vans are the best options. Closed vans without refrigeration should never be used to transport cones and seeds! The field supervisor should verify that each cone sack is properly tagged, provide an inventory by seed lot, and notify the extractory of the estimated time of arrival to expedite unloading of cones.

STEP 5 – Cone and Seed Processing

Cone and seed processing begins with the arrival of cones at the extractory and ends when the upgraded seed lots are entered into long-term storage. When cones arrive at the processing facility the cone/seed lot inventory and identification tags are verified and corrected, if required. Any cone sacks that may have been damaged in the field or during transport are identified and replaced to prevent loss of seed. A random and representative sample is withdrawn for a pre-conditioning assessment using the cutting test procedure described earlier. Adequate sampling is a must – a sampling of cones from ten percent of the cone sacks is standard. For example, a 100 bushel cone lot necessitates a minimum of several cones from each of ten individual sacks, randomly selected. This assessment will address the current condition of the cone lot: maturity level, insect and disease activity, potential yield, and need for proper cone curing. It will also provide the basis for prioritizing processing timing and define the subsequent cone and seed handling activities necessary for a successful outcome.

For most species, cone and seed processing involves several standard steps: drying (air dry, then kiln), extraction (cone tumbling), pre-cleaning, de-winging, seed processing and upgrade (with screens, pneumatic separator, or gravity table), final cleaning, and seed drying, if necessary. A schematic is presented in Fig. 5.37.

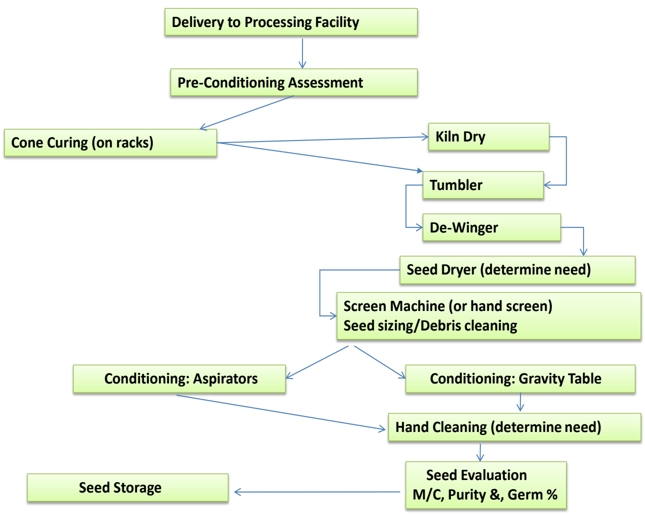

Figure 5.37 Typical cone and seed processing flowchart, sequence may vary.

Figure 5.38 Cones air drying on racks in a cone shed.

Cone Curing

Once delivered to the extractory, the cone sacks are spread out on steel mesh racks and stored under an open sided structure out of the direct sun and rain but exposed to good airflow from all directions (fig. 5.39). The sacks are turned every other day to promote gradual moisture loss and uniform curing and to prevent overheating and fungal growth. The mesh sacks permit visual monitoring of cone curing progress. As cone drying continues and the cone scales open and release their seeds, the frequency of sack turning may be reduced over time to one or two times per week. The length of cone storage (curing) varies by species and initial cone condition, but is typically two to four weeks.

Kiln Drying

Kiln drying refers to the cone drying process in which temperature, air flow, and in some facilities, relative humidity are carefully controlled. Kilning causes the cone scales to flex and open, allowing the seeds to be extracted. The temperature and duration of kilning may vary by species and cone condition but is generally effective between 32-37^{o}C and 14-18 hours duration. It is important that cones be properly air dried before kilning to avoid a condition called case- hardening; the result of the outer layers of the cone drying more quickly than the moist interiors. In case-hardened cones, the scales freeze in a partially open position and trap the seeds inside causing significant to complete loss of seed yield.

There are two main types of kilns: batch kilns and rotary kilns. The batch type involves placing a thin layer of cones into trays fitted with a screened bottom, stacking the trays four to six high and capping the top box. The trays are placed onto plenums in the kiln which allow for heated air to course through the stacks of trays evenly at moderate velocity. The operational size kiln at the L.A. Moran Reforestation Center is capable of drying up to 300 bushels of cones from multiple seed lots at one time (fig. 5.39). A rotary type kiln combines drying and tumbling in the same phase and releases the extracted seeds from the drum to exit the heated and dry environment (fig. 5.40). The rotation speed and duration can be adjusted but this kiln type is restricted to processing a single seed lot at a time.

Figure 5.39 (left) Batch Kiln - kiln boxes loaded onto plenums for cone drying (LAMRC, Davis).
Figure 5.40 (right) Rotary Kiln, conveyor and cone tumbler (USDA Forest Service, Placerville).

There are variations to the above, of course. Species with serotinous cones, for example, generally require a hot water treatment and high temperature kilning to break a resin seal that prevents the scales from opening readily. One effective treatment is a 60-second boiling water dip followed by 18 to 20 hours of kiln drying at 50^{o}C. Alternatively, serotinous cone collections may be delayed until early spring when the cones still retain significant moisture from the recent wet season. These cones will generally open with kilning alone, without the cumbersome and time consuming hot water treatment.

Another processing variation involves species that have soft and fragile seed coats. These types of seeds are prone to serious damage, especially to the resin vesicles in their seed coats. True fir and incense cedar are especially sensitive to heat and are easily damaged in a kiln. They may also sustain mechanical injury during de-winging and screening; all of which makes them particularly challenging in the extractory. When true fir cones have been allowed to dry naturally on racks, little or no additional drying may be needed because the cones disintegrate rather than flex to open and the seeds generally separate from the axis and scales readily. If kilning is necessary, the cones are spread out sparingly in the drying trays, the temperature should be ambient (may not exceed 30-32^{o}C), and kilning should be of short duration. Subsequent tumbling is usually cursory to separate the scales from the winged seeds or to help break apart any cones that did not dehisce during drying.

Incense cedar is best dried naturally in mesh sacks arranged flat on racks in a shady, well-aerated area. The sacks may be turned periodically for even curing but in a lifting and rolling motion, very carefully, to avoid piercing the seed coat and resin vesicles with needles or other sharp debris that may be present. Extraction is handled in small batches in a screened drum which separates the trident-shaped cones from the seeds. Alternatively, incense cedar cones may be separated from the seeds using hand screens.

Tumbling

Following batch-type kilning, the cones are transferred to a tumbler for extraction. The tumbler drum is fitted with a mesh screen sized to allow the seeds to fall through to a container below while the drum rotates and spent cones are disposed of through an opening in the drum at the end of the rotation. The length of the tumbling phase is vital to seed lot yield and quality; removal of all viable seeds is essential but the process must stop short of damaging seeds through excessive tumbling or introducing excessive debris from broken cones and scales into the seed lot. After a seed lot is passed through the kiln and tumbler, the seeds may be temporarily collected in rigid plastic boxes or fiber drums and interim-stored in a cooled environment (3-5^{o}C) to facilitate easy handling of seeds during subsequent processing steps. The cool temperatures also are effective in slowing down insect activity in a seed lot when it exists.

Screening

After seeds are separated from the cones, seed lots that contain considerable debris may be passed through a screen machine with air flow over a series of slotted, round-holed or mesh screens to pre-clean the lot before further processing. Screen size and shape is varied to suit the species being cleaned and the debris that is being removed. This process is called scalping and it is effective at removing cone scales, needles, pitch, small rocks, and other inert matter that could cause injury to the seed (fig. 5.41). Incense cedar <u>is not</u> screened using this process to avoid unnecessary damage.

Screening may also be done with a variety of hand screens similarly fitted with different sized openings that allow the target material to pass through. Note that a custom determination of screen size and shape is needed for each seed lot, even if the species is the same, since size of seed and debris may differ. Pre-cleaning the seed lot increases the efficiency of the processing steps to follow. Incense cedar is commonly screened using hand screens.

De-winging

De-winging is the process that removes the seed wing from its attachment to the seed coat. Seeds of most species may be de-winged by one of several methods. By far the majority of species are de-winged using a rotary drum specially designed to control rotation speed and angle and apply moisture if needed (fig. 5.42). Species that are "wet" de-winged include some pines and spruces which have seed wings that are weakly attached to the seed coat via the integument. To remove these wings, a short spray of water mist is intermittently applied while the seeds are rotating in the drum, causing the seed wing to expand at this connection and cleanly detach from the seed coat. In a slightly different scenario the seed wings of true fir and Douglas-fir, which are an integral part of the seed coat, must be broken off by mechanical friction. De-winging of these species is done with no added moisture – the paddles within the rotating drum allow the seeds to gently roll over one another, breaking the wings, though somewhat imperfectly and frequently incompletely. If the seed moisture content is high, then drying the seed lot to below 15 percent of fresh weight may result in a more brittle seed wing and more complete de-winging. For both wet and dry de-winging methods the seed wings then may be gently blown off in the de-winger with an air hose set on low or separated later with a pneumatic separator. It is important to note that an oil-free compressor should be used for blowing. Alternatively, removing the seed wings of small size seed lots (hard-coated seeds only) may be done by gently rubbing the seeds between one's hands. For each method listed it is important to avoid prolonged de-winging to minimize seed injury through bruising or abrasion. Seeds with resin vesicles such as *Abies spp.* are particularly susceptible to damage. It is recommended that de-winging be carefully monitored and be as brief as practical.

Figure 5.41 (left) Screen machine (or Scalper). **Figure 5.42** (right) Custom seed de-winger.

Figure 5.43 Incense cedar seed with radicle emerging from wing end. *Photo*: Dorus Van Goidsenhoven, CAL FIRE

Several species in California are not routinely de-winged. Incense cedar seed is one; the embryo is reversed in incense cedar with the radicle emerging from the seed wing end (fig. 5.43). This anatomical anomaly makes significant damage to the seed unavoidable with attempts to remove the wing. Lastly, there are several genera including *Sequoia*, *Sequoiadendron*, and *Cupressus*, which have very small seed wings that are tegumentary extensions of the seed coat and no attempt is made to remove them. The damage to these seeds would be severe.

Seed Upgrade

Seed processing deals with upgrading the seed lot. The reasons for upgrading seed lots are many and include the following: reduce bulk and weight, increase seed lot purity, increase germinative capacity by removing empty and damaged seeds, improve seed storage life, and make seedling production easier and more economical. Seed upgrade removes empty, immature and non-viable seeds, plus any fine debris that may still contaminate the seed lot. There are two main types of mechanical separators commonly used for this purpose: the pneumatic separator (also known as an aspirator or air separator), and the gravity table.

The pneumatic separator utilizes an adjustable air column fitted with a vacuum, or blower. A vibratory feeder is used to deliver the seed into the air column (fig. 5.44). Seeds are separated based on differences in weight. The air velocity can be manipulated to capitalize on the differences between the target seeds and the debris being sorted. There are several outlets for seed discharge in descending order of material weight (product-heaviest — lighter — lightest). An x-ray radiograph or cut test is used to calibrate the air flow settings and determine if the separation is acceptable; each seed lot requires its own unique settings. The goal is to separate the heavier seeds which are presumed to be filled and viable from lighter fractions which may contain partially filled, empty or otherwise undesirable seed and debris. While it may be tempting to use a stronger airflow setting to remove a greater quantity of empty or partially filled seed or debris, care must be taken not to use too strong an airflow if it also removes a significant number of small, filled seed with similar weight to larger but empty seed. Inadvertent removal of the smaller filled seed component would effectively reduce the genetic base one has worked so hard to achieve. If necessary, it is possible to re-run the seed in a discharge bin with an adjusted airflow setting when it contains a combination of filled and undesirable seed. Seed lots are often run through an air separator more than once with progressively finer-tuned settings to achieve the desired end product.

The vibratory feeder speed can influence upgrade results as well. Excessive speed may result in too much seed in the air column at one time, preventing the light seed from being drawn up into a discharge fraction. A slower vibratory feeder speed may permit a better separation but may take much longer and tie up the separator. A proper balance between processing efficiency and processing accuracy is desired. Pneumatic separators are available in various designs and sizes (fig. 5.45).

Figure 5.44 Wall-mounted pneumatic separator (vacuum version).

Figure 5.45 Four-chamber forced-air separator (free-standing).

Figure 5.46 Air gravity table.

The gravity table utilizes an inclined deck that moves in two directions – up and down, and backwards and forwards. The deck is covered with a mesh cloth that allows an air current below the deck to move the seeds based on specific gravity (fig. 5.47). When seeds are lighter they are lifted off the deck slightly and move toward the lower end of the deck. If the seeds are heavier and in contact with the deck, they move toward the upper end of the deck and can be collected in different fractions based on placement of dividers on the deck that are manipulated by the operator and based on seed weight. The seed lot is separated into heavy, light, and lighter fractions and collected in separate bins. An x-ray radiograph or cut test is used to calibrate the air flow and the settings related to deck tilt and the position of the dividers. Each seed lot requires its own custom setting. It is common to run a seed lot more than once with adjustments to these settings. A gravity separation can be an effective option for species that are more vulnerable to damage such as true fir, but the equipment requires a highly experienced operator to manage the many variables of the different settings and for a successful outcome.

Incense cedar seed poses a challenge to seed processors at every stage. Mechanical separation tends to be harsh on the delicate seed coats. A series of hand screens with slotted openings may be used to dispose of debris and the flat (empty) seeds, but care must be taken to avoid rubbing the seeds against the screen and causing damage to the seed coat and resin vesicles. The intact seed wing makes air separation challenging as well because of the natural lift of the wing by the air column, but it can be done. Incense cedar seed is easier to work with when chilled at 2 to 4^{o}C prior to separation. Using a slow speed on the vibratory feeder and a low vacuum setting for a light separation, the air column will pull light and empty seed up and out of the column with minimal effect on the wings of heavier (filled) seeds. The process is purposefully slow but suitable for smaller seed lot sizes (20 bushels or less) with minimal damage.

Hand cleaning a seed lot is the final stage in seed processing and cleaning. It is important to maintain a strict purity standard of 98 percent or higher of pure seed per unit weight for a variety of reasons: purity percent is one of the essential parameters when determining quantity of seed needed for nursery sowing; removal of impurities reduces bulk and the amount of storage space needed; and fewer impurities reduces the potential for injury to seeds in storage. After final cleaning, the seed lot is mixed thoroughly for homogeneity before testing and extended cold storage.

In each stage of cone and seed processing and upgrade, one must be careful not to over-process; seeds that do not possess a hard protective seedcoat are particularly susceptible to damage from heat, bruising, breakage, and abrasion. In practice, seeds should not be handled when conditions are too warm or if the seeds feel “sticky”.

Avoid cross-lot contamination. The most important consideration during each of the cone and seed processing steps is to avoid contamination between seed lots. A thorough cleaning of all equipment and tools used is essential and may involve any or all of the following: vacuuming, brushing, sweeping, blowing, electrostatic cleaner, de-pitching, steam cleaning, and sterilization.

STEP 6 – Seed Lot Assessment

Analytical tests are performed on seed lots to determine:

- moisture content
- seed purity percent
- seeds per pound
- percent filled (by x-ray)
- germination percent

The most significant aspects of good seed testing are proper sampling and uniform testing procedures. Guidelines for these tests and sampling procedures are found in the Association of Official Seed Analysts (AOSA) and the International Seed Testing Association (ISTA) rules. These tests provide the basis for seed lot evaluation and for determining the number of seeds needed for sowing in the nursery. Additionally, knowledge of the quality of the seed lot(s) and the number of potential seedlings available in storage for reforestation is crucial to future collection planning efforts.

Sampling

Sampling, first and foremost, must be random and truly representative of the entire seed lot to be of value. Drawing the sample may be done with a seed probe (or trier) or by inserting an open hand into the seed lot to a sampling point and withdrawing the closed hand. If there are one to five containers, a primary sample must be taken from each and mixed thoroughly; if there are more than five containers, five of them plus ten percent of the remaining containers are required. This blend of primary samples constitutes the composite sample from which a smaller “working sample” is taken (approximately 2500 seeds). Sampling and seed testing are routinely conducted on-site at seed processing facilities in California rather than shipped to a separate seed lab for testing; therefore the sampling procedure described above to obtain the working sample follows the seed moisture test. After seed moisture content has been determined to be in the “safe” storage range of 5 to 9 percent, the working sample may be drawn.

Moisture Content

Measurement of seed moisture content is vital in preparing seeds for long term storage. Moisture content is the most important factor in viability retention. Correct low moisture content and low storage temperature assures metabolic rates are minimal and fungal and insect activity ceases. If seed moisture content exceeds the standard 5 to 9 percent threshold for storage, the seed lot must be dried down by one of the following methods: kiln drying for larger lots, small lot seed dryer, or solar drying. Seed moisture content may be measured by one of several methods including the oven-dry method or a rapid method using an electronic moisture meter. The oven-dry method is a destructive test but is acknowledged to be the most accurate. In the oven-dry method, duplicate samples of 5 g each per seed lot (3 g each for RW and GS) are dried in a forced-draft oven (for even, accurate drying) at 100^{o}C for 17-18 hours. It is important to use an accurate balance to three decimal places. At the end of drying, the samples are covered with a close fitting lid and cooled to room temperature (30 to 45 minutes), then re-weighed. The moisture content is expressed as the difference between the fresh weight and dry weight of the seeds, as a percentage of the fresh weight:

$$\text{Moisture content} = \frac{\text{fresh weight} - \text{dry weight}}{\text{fresh weight}} \times 100.$$

If the difference between the two samples exceeds .03%, ISTA rules require that the procedure be repeated.

An electronic moisture meter (Dole Meter Grain Tester) is one type of quick test and is generally accurate to within +/-1 percent of the oven dry value. It is non-destructive and commonly used for small seed lots or for a quick moisture check during processing. Logical timing during seed processing when a moisture check may be appropriate includes after “wet” de-winging or during an air separation run in which an effective separation falls short of expectation. Moisture values using a Dole Meter are generally more accurate when the seed is at room temperature. A disadvantage of the Dole Meter is that it requires calibrated values for each species that must be determined in advance. Calibrations have been done for the following: bishop, coulter, Jeffrey, Monterey, ponderosa and sugar pines, coast redwood, giant sequoia, grand, white, and red fir, Douglas-fir, and incense cedar. Moisture content also directly influences the relationship of weight to the number of seeds of a specified quantity, so the seed lot should be in the 5 to 9 percent moisture range before further tests are done.

Seed Purity Percent

The seed purity test defines the composition of a seed lot based on the weight of pure seed and the weight of any impurities contained within it. Using the working sample, one thousand seeds are counted out in groups of 100 and maintained in separate piles. Other crop seed or debris that is associated with the sample as it is counted are maintained as separate components. If cracked, broken or otherwise damaged seed is encountered, it is counted as crop seed if it comprises more than one-half the size of the seed. Damaged seeds in the bulk lot will reduce the germination percent and must be included in the purity and seed count determinations. The fractions are weighed separately and the purity is expressed as a percentage of the total weight:

$$\text{Purity percent} = \frac{\text{weight of pure seed (g)}}{\text{weight of pure seed + other crop seed + debris (g)}} \times 100.$$

The purity percent standard for tree seed at the L.A. Moran Reforestation Center in Davis is ≥98 percent. If impurities or overall debris comprise two percent or more of the seed lot, further cleaning is required.

Seeds per Pound

The number of clean seeds per unit weight of the seed lot (in pounds) is calculated using the pure seed and companion components from the final purity test:

$$\text{Seeds per pound} = \frac{\text{\# of seed/Lb.}}{\text{g/Lb (453.6)}} = \frac{\text{1000 seeds}}{\text{weight of pure seed + debris (g)}}$$

$$(\text{\# of seed/Lb.}) \times (\text{weight of pure seed + debris in g}) = 1000 \times 453.6$$

$$= \frac{453{,}600}{\text{weight of pure seed + debris (g)}}$$

The purity percent and seed per pound calculations are important factors for determining nursery sowing requirements. However, they do not provide any information relating to the tree-producing capability of the seed lot.

X-ray Technology

Since the mid-1980s, the use of high resolution x-ray images has become an increasingly important tool for initial evaluations and in the processing, upgrade and analysis of conifer tree seed. Radiographic images are non-destructive, as opposed to cutting tests, and provide valuable information on the interior morphology of the seed and the presence of insect larvae, abnormalities or disease. The x-ray cabinet component utilizes low-energy (soft) x-rays only and is deemed safe when personnel are properly trained and using appropriate precautions. The risk of damage to seeds by x-ray is considered minimal to none. Digital systems are available that can enlarge the image of the seed to allow more definition and apply coloration to tissues based on density. Long term storage and transfer of digital images has become convenient and routine. Preliminary and periodic x-ray images are used to determine appropriate settings for seed processing equipment and also to confirm separation progress during upgrade (fig. 5.47). Small seed lots, or especially valuable or delicate seeds that may be damaged using mechanical separation methods, may be sorted using celled acrylic trays that enable hand selection of higher quality seed. Blister rust resistant sugar pine seed lots and seed lots of endangered species have been processed using trays and hand selection (fig. 5.48).

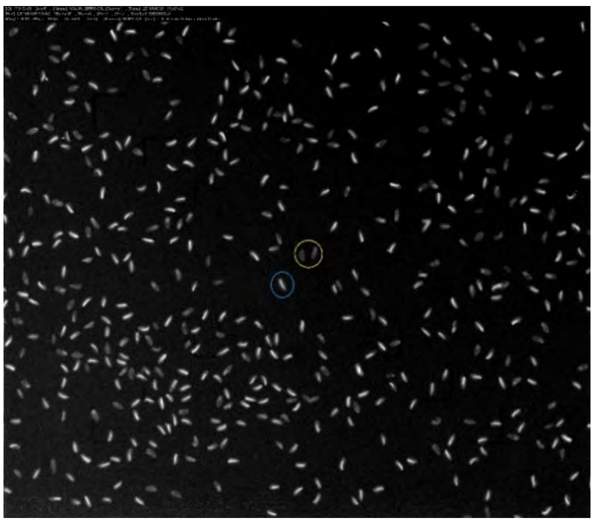

Figure 5.47 Giant sequoia seed (filled seed-blue circle; empties – yellow circle).

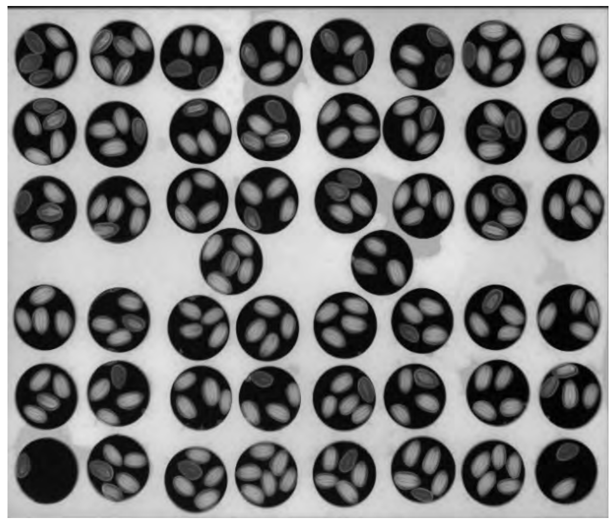

Figure 5.48 Sugar pine seeds trayed for upgrade, by x-ray. The empty and damaged seeds are removed using forceps.

The pure seed component from the purity and seed per pound analysis, above, allows the seed technician a quantifiable means to estimate germinability of the final seed lot, via x-ray image, and compare it to the laboratory germination result. Initially, interpretation of x-rays may be subjective, but over time the seed technologist acquires the aptitude to reliably correlate an x-ray image versus a germination test result. Admittedly, such correlations are better for some species such as redwood and less reliable for others, such as white or red fir.

Germination Percent

The laboratory germination test determines the quantity of seedlings that may be produced from a seed lot under optimal, controlled conditions. The germination capacity (GC) is the chief standard used to define seed lot quality – this is the percent of seeds that germinate normally during a specified period, usually 28 days. The germination value (GV) is a measure of vigor, or speed of germination. An official germination test consists of 400 seeds (four replicates of 100 seeds each) selected at random from the pure seed component of the purity and seed per pound analyses (fig. 5.49 and 5.50). A second 400-seed test is reserved for a germination retest after one year in long term storage and is enclosed within the storage container that holds the bulk seed lot until needed. Subsequent germination tests are conducted at three to five year intervals to insure that recent and reliable test data is available for nursery growing.

Figure 5.49 (left) Coulter pine seed germinants (day 7) on moist substrate (perlite). **Figure 5.50** (right) Ponderosa pine seed germinants (day 14) on moist substrate (cellulose paper)

Figure 5.51 White fir seed germinants (day 14). Germinants on left (3) show normal development of hypocotyl and radicle. Germinants on right (3) show abnormalities (stunted tissues) and fungal growth (middle-right.).

Not every seed that germinates is included in the germination count; only those that are defined as normal according to the standard guidelines (AOSA). A normal seedling is described as one that possesses the essential structures that indicate its ability to produce a normal plant under favorable conditions. The most common abnormalities identified in a germination test include a breached embryo, in which the cotyledons emerge before the radicle, stunting of tissues such as the hypocotyl or the radicle, or rapid internal fungal growth (fig. 5.51).

Germination percent is calculated by the following:

$$\frac{\text{Number of normal seedlings}}{\text{Number of seeds sown}} \times 100 \text{ (nearest whole number; do not round up)}$$

The four replicates are compared - if they are within the accepted range of tolerance established by the rules, the average of the replicate values is the germination result for the seed lot. If the replicate values are not within the established tolerance, the germination test must be repeated.

Standardized germination tests are designed to provide ideal conditions for maximum values with minimum variation and achieve results that are reproducible. The pretreatment regimes that have been adopted as the recommended procedure for each species are the result of research and comparative tests over time that produced the highest germination results with the least variation.

Standard testing protocols for several conifers in California are listed in Table 5.5.

Seed Dormancy

Seed dormancy is a condition of viable seed that prevents it from germinating even when exposed to suitable environmental conditions. Dormancy is the mechanism in conifer seeds that eliminates the risk of immediate germination after natural seed fall in autumn when conditions are generally unfavorable for growth and survival. Most California conifer seeds have the type of dormancy known as morphological (or physiological) dormancy. This type of dormancy is thought to be a consequence of immaturity within the internal seed tissues. In nature, the cool moist conditions of winter allow the seed to absorb moisture and advance the after-ripening processes, allowing germination the following spring. These conditions are mimicked in the seed lab and forest nurseries by soaking the seeds in water followed by moist chilling in a refrigerated chamber at the appropriate temperature and duration determined by experience for each species (Table 5.5). This process is called stratification or moist pre-chilling - the terms are used interchangeably here. In some pines, such as Coulter pine and foothill pine, the seed coat thickness may act as a barrier to moisture and oxygen exchange and can delay swelling and imbibition of the embryo. This type of seed coat dormancy is overcome simply by a longer soak in room temperature water (48+ hours). The longer water treatment tends to soften the seed coat and allows for imbibition which is then followed by an extended period of stratification.

Table 5.6 Germination protocols recommended for the listed species

Species	Imbibition # hours	Stratification [a] # weeks	Special Protocols	Germination Light-Dark [b] Temp °C	Test Duration # days
White fir, grand fir	24	6		25-15	28
Douglas-fir, Coast redwood, Monterey cypress	24	6		30-20	28

Red fir, Shasta red fir	24	10		25-15	28
Incense cedar, Bigcone DF, Sitka spruce, Tecate cypress	24	8	—	30-20	28
Giant sequoia	48*	6	*Running water rinse	30-20	28
Lodgepole pine	24	4		30-20	28
Ponderosa pine (low-high el.)	24	(4-8)		30-20	28
Ponderosa pine – orchard	24	8		30-20	28
Pinyon pine, Santa Cruz cypress	24	12		30-20	28
Jeffrey pine, Knobcone pine	48	6		30-20	28
Coulter pine	48	10		30-20	28
Torrey pine, Western white Pine	48	12		30-20	28
Sugar pine	48*	13-16	*Running water rinse	30-20	28-35
Foothill pine	48	16		30-20	28

[a] *Cold stratification is most effective between +2 and +4 degrees C.*

[b] *8 hours at higher temperature with illumination and 16 hours at lower temperature in dark.*

Methods to Prepare Seeds for Germination in the Laboratory

The degree of dormancy and the optimal length of stratification varies greatly between species and also among families of the same species, though differences among the latter can generally be attributed to geographic origin and latitude or elevation of the seed source. Moisture availability is the primary factor controlling germination. The optimal moisture content for seeds to overcome dormancy during stratification is between 30 and 35 percent. This moisture level is achieved by soaking or rinsing the seeds for the specified period, changing the water daily if more than 24 hours. For species requiring a running water rinse or bath, this is effectively done with mesh sacks in non-recirculating water and aerated with a bubbler from a small pump. The running water rinse is an effective strategy to remove fungal inoculum from seed coats, namely *Fusarium spp*. from sugar pine seeds and *Botrytis spp*. from giant sequoia seeds.

After soaking, the seeds are drained thoroughly and allowed to surface dry on blotter paper then placed into a dry zip lock-type bag for the duration of the moist prechill period at 1 to 2^{o}C. There should be no fruit in the refrigerator used for the prechill, since ripening fruit gives off ethylene gas that is detrimental to germination. For proper aeration, the bags should have sufficient airspace above the seeds and should be turned at least weekly for the duration. After stratification an appropriate number of seeds are counted out and placed in closed, transparent boxes on a sterile, moist substrate where the roots may grow and be examined without damage. The closed boxes help to maintain the high seed moisture content, but the substrate should not be so wet that it restricts aeration, nor be allowed to dry out and cause seed desiccation. The seed analyst, when placing seeds onto the substrate, must leave space between each to reduce the potential for transfer of seedborne pathogens.

The temperature and light conditions within the laboratory germination testing cabinet or chamber are carefully controlled. The temperature in the germination cabinet primarily affects the rate of germination and is set to alternate with lows at night (16-hr dark cycle) and highs during daylight (8-hr light cycle) hours. The alternating light effects are thought to benefit germination in conifers seeds but are strongly related to and difficult to separate from the temperature effects.

For germination capacity (GC) the germinants are counted every seventh day for the duration of the test. Any abnormalities or decayed seeds are recorded as well. If there are a number of firm, un-germinated seeds at the end of the test, it may be extended an additional week to allow for more complete germination. The delay may indicate that the seed lot requires more prechilling and it should be noted in the record. For germination vigor testing, or germination value (GV), the counts are more frequent, usually three times per week.

Note: Rapid tests i.e., tetrazolium (TZ), excised embryo, etc., are not discussed here. See selected references for details on the different types, methods, and limitations of rapid tests. (Bonner 1994) (Bonner, Karrfalt, 2008).

Variations among Species

There are variations in germination rate expectations among conifer species in California. The variations appear, in part, to be related to seed morphology. The woody seeds of pines and Douglas-fir tend to germinate more readily and at higher rates, once impediments to dormancy are overcome, than seeds with softer seed coats. However some species of pine with deeper dormancy requiring a longer stratification period are known to have lower and sometimes erratic germination, i.e., western white pine and foothill pine. The soft seed coats of true fir and incense cedar, and the resin vesicles within them, are easily damaged by heat, poor handling, or by equipment used during processing. These species tend to have more non-viable seeds included in a seed lot not only because of this delicate nature, but also because of the tendency of seed processing staff to avert undue damage from excessive processing which results in more unfilled seeds in the lot. True fir seeds also tend to have a higher rate of defects such as reversed embryos and radicle irregularities.

Coast redwood and giant sequoia naturally tend to produce a high percentage of cones with empty or tannin-filled seed, often exceeding 70 percent non-filled. The seeds are extremely small and light-weight, offering little difference in seed weight (or specific gravity) between the viable and tannin-filled seeds. This tendency poses a significant challenge for a successful separation outcome between the filled and unfilled seed fractions. Continued attempts to upgrade will at first increase filled seed percent but will eventually cause a loss of viable seed as well.

The overarching goals of the CAL FIRE forest tree seed bank in California are to promote resiliency in a changing environment and to maintain a sizeable inventory of site-adapted seed of the broadest diversity and highest quality for reforestation, emergency restoration, gene conservation and climate change mitigation. To that end, minimum germination standards have been established for general population seed lots below which the seed may be culled and scheduled for replacement (Table 5.7). Exceptions are made for improved genotypes, other special accessions, and seed from zones with infrequent production (low periodicity). High quality seeds are essential for producing vigorous seedlings for outplanting and must be readily available for nursery production when they are needed.

Note: With a changing climate and the resulting uncertainties, there may be less frequent and more sporadic cone crops and perhaps even fewer filled seed and lower quality seed. In future, this may mitigate against culling seed that has decreased to minimum germination standards until sufficient replacement seed of better quality has been obtained. However, it must be understood that if lower quality seed is retained, it will have decreased storability, decreased germination capacity and vigor, and decreased seedling production value.

Table 5.7 Minimum germination standards for the listed species

Species	Germ % (minimum)	Goal % Filled [a]
Coulter pine, Jeffrey pine, ponderosa pine, knobcone pine, bishop pine, Douglas-fir, Bigcone Douglas-fir	80-85%	95%
Sugar pine, Torrey pine, foothill pine, western white pine	75-80%	95%
Incense cedar, white fir, red fir	60-75%	80%
Coast redwood, giant sequoia	40-50%	70%

[a] *Post-upgrade seed lot goal (x-ray percent)*

The Relation of the Seed Laboratory Germination Result to the Nursery

The nursery seed user must relate the seed lab results they are provided with to seed lot performance in their operation under local conditions. Over-sowing results in waste of valuable seed, disease problems brought on by high seedling densities, and in labor intensive activities such as thinning. Under-sowing wastes time, growing components, growing space and water, and results in fewer seedlings than contracted for. Both situations are unacceptable. Standardized seed testing procedures and dependable germination results from the seed lab have led to more reliable methods of calculating sowing rates and schedules in nursery operations.

Germination capacity - the germination result most often supplied by the seed lab - doesn't always provide all of the necessary details for success in the nursery. The lab germination test is designed to be a maximum under ideal, controlled conditions and may need to be adjusted downward based on nursery conditions. Nursery sowing, where germination environments are almost always more variable and less favorable than in the laboratory, may require a longer (or shorter) prechill. In addition, there are different criteria for gauging germination between the two. In the lab, a seed is considered germinated when the radicle is four times the length of the seed and all seed components appear healthy. This stage generally occurs between day seven and day 14 in a 28-day germination test. In contrast, the nursery judges germination at a point farther along in the seedlings' development when the cotyledons have emerged from the seed coat. Abnormalities or failures occurring at this later stage often are not considered in the laboratory evaluation. Another factor to consider is seed age and length of time in long-term storage. As seeds age, they begin to show signs of deterioration. Seed vigor declines more rapidly than viability. Therefore, a vigor test (germination value) may provide valuable insight in how best to care for the seed lot in the field. Seeds of low vigor often germinate better with a shorter prechill; normal prechill of such lots may decrease germination (Bonner 1994).

Other nursery cultural factors such as priming and sanitation practices may affect survival and cull as well, and must be accounted and prepared for. The nursery seed user must establish a survival factor unique to his/her nursery operation through a series of trials, experiments, and history plots which, over time, establishes the survival statistics that become the basis for calibrating the differences between the laboratory and nursery practices.

Testing and Trials – Lessons Learned

Seed germination test and nursery operation outcomes provide numerous opportunities to conduct in-house trials that examine the efficacy of different treatments on seeds of many species. For example, past imbibition trials largely determined the amount of water uptake that is necessary for metabolic processes to begin for a variety of species without raising moisture levels too high and contributing to anaerobic conditions. The result was a significant reduction in soak times for a variety of pines including Coulter, foothill and knobcone, and was accompanied by higher germination values and minimal losses to fungal disease. In another trial that looked at improving germination of true fir through longer stratification periods resulted in refined germination outcomes for white fir based on seed condition and elevation of source. Similar improvements in germination values for white fir seed were realized by exploring different temperature regimes in the germination chamber (alternate and constant) for a variety of species - this trial resulted in the adoption of lower temperature parameters (25-15^{o}C) for *Abies* seed.

One pre-treatment method developed in British Columbia, known as “stratification-redry”, was used to determine the optimal moisture conditions and pre-chill period necessary to break dormancy in California red fir seed (including *var. shastensis*). The result was a measured moisture threshold between 30 and 35 percent, post-imbibition, and an extension of stratification from six to ten weeks that consistently achieved more rapid and uniform germination while also decreasing fungal issues and early germination in stratification.

Another noteworthy study looked at sterilization treatments to reduce seed surface pathogens on a variety of species when seed germination was low. Sterilants frequently used on hard-coated seeds have included varying solutions of sodium hypochlorite (2.5% household bleach) and hydrogen peroxide (H_2O_2) given that seeds are undamaged and rinsed thoroughly after treatment. The effect of surface sterilization with bleach on select conifers was mostly mixed but found to be harmful in many instances. However, a solution of 3% H_2O_2 was found to reduce levels of fungal inoculum in ponderosa pine when seed quality is low and the procedure has been adopted when seed source is of high value or scarce. A running water rinse in a non-recirculating water bath to remove fungal spores is considered safest for soft-coated seeds and has effectively improved germination in species susceptible to damping off fungi such as *Botrytis* and *Fusarium spp*. In all, the most successful outcomes of these treatments and trials and others have led to adoption as the standard practices and they have contributed to better results in the seed lab and more successful outcomes in nursery operations.

Note: Nurseries have also found that extending stratification periods beyond those in the testing standards may result in improved germination vigor for high quality seed lots with no reduction in germinative capacity (personal communication, Jopson 2017)

Step 7 – Long-term Storage

The Objectives of Long-term Storage

The objectives of long-term seed storage are:

1. To have a viable seed supply when it is needed for regeneration and,

2. To delay deterioration, or at least decrease its rate, until the seeds are needed or can be replaced by the next good seed crop.

Tree seed storage has been an important topic of research for many years and effective storage methods have been established for certain classes of seeds. For seeds of species that can be stored, proper storage conditions are critical to maintaining seed viability over an extended period. The two most important factors affecting success in long term storage are seed moisture content and storage temperature.

Orthodox or Recalcitrant

Conifers and other woody plants are generally classified as “orthodox” or “sub-orthodox” (intermediate) in their seed storage behavior. Orthodox species are tolerant of desiccation (below 10 percent of fresh weight) and may be stored for long periods (usually 20 to 25 years or more) without loss of viability. This type of seed tends to have a hard or woody seed coat that provides good protection from damaging agents. A hard seed coat also restricts moisture uptake and gas exchange that could contribute to seed deterioration. The best seed moisture range for successful storage is between 5 and 9 percent. *Pinus*, *Picea*, *Pseudotsuga*, and *Tsuga* are among species in California described as orthodox in storage behavior.

Sub-orthodox species also tolerate desiccation and sub-freezing temperatures but storage is limited to shorter periods (usually less than 15 years). This type of seed tends to have a thin, permeable seed coat, a higher lipid content rather than starch, and resin vesicles. These characteristics make them more susceptible to damage and therefore harder to store. Seeds of *Abies, Calocedrus, Sequoia and Sequoiadendron* may be described as sub-orthodox in storage behavior though some still consider them orthodox. Incense cedar seed is particularly sensitive to damaging agents and must be handled with extra care. Successful storage of incense cedar seeds is typically less than ten years.

Seeds of woody species that are classified as “recalcitrant” in storage behavior tend to be fleshy and will not tolerate drying below rather high moisture levels without losing viability. The seed moisture content must remain at 30 percent or higher and requires storage temperatures above freezing. These conditions allow for continuation of metabolic activity but also promote rapid fungal growth. This type of seed is best collected fresh in years when it is available and sown directly. Species known to be temperate recalcitrant include *Quercus*, *Umbellularia*, *Arbutus* and *Aesculus*.

Note: Cryogenic storage in liquid nitrogen may extend storage life, but it is not a practical method for bulk seed lots or in these applications and is not detailed here.

Seed Longevity in Storage

Seed longevity is a measure of:

- seed maturity at the time of collection
- seed quality
- seed morphology
- genetics
- pre-storage handling and treatment
- proper conditions of storage

Seed maturity indices and timing of collections are very important when considering long term storage potential. Fully ripened seeds retain viability longer, are less susceptible to handling damage, and have longer storage capability. Immature seeds tend to dry out rapidly, damaging vital tissues. They are also more likely to have low vigor and be more susceptible to disease.

Seed life expectancy varies greatly among different species of conifers. These differences are, in large part, related to seed morphology. A hard seed coat protects the embryo from mechanical injury and minimizes metabolic rates in storage by excluding moisture and oxygen when the seed is properly dried. For example, there are hundreds of pine and Douglas-fir seed lots that have been stored in the CAL FIRE forest tree seed bank in Davis, CA at sub-freezing temperatures for more than 35 years with minimal reduction in viability over this period. In contrast, seeds with a soft, permeable seed coat are more likely to suffer bruising of sensitive tissues or be subject to moisture uptake, both of which contribute to seed damage and storage difficulties. In germination trials over several years, it was found that many *Abies* seed lots from a variety of seed zone and elevation sources retained high viability status for a minimum of 15 years (in-house records, LAMRC unpublished. 1998). However, *Abies* seed with lower quality status generally presented greater germination decline over a shorter period of time.

Environmental stress during cone and seed development and maturation such as drought or nutrient deficiencies in the maternal parent may limit shoot growth, thus adversely affecting seed quality and storage potential.

Genetics also plays a role in seed quality - some trees are reliably better cone producers than others. It is believed that individual tree fecundity is an inherited trait, likewise influenced by the maternal parent.

Pre-storage handling that causes damage to seeds leads to reduced seed viability in general and particularly after any length of storage. Probable handling practices to watch out for include:

- impact damage during collection

- physiological overheating of cones or seeds at high moisture content during transport or kilning
- excessive tumbling, screening or de-winging that may cause bruising or breakage
- failure of coolers during interim storage

An undetected crack or other opening in a seed coat may allow invasion of harmful pathogens and cause certain loss of viability in the short and long term.

Proper Conditions of Storage

Seed moisture content is the most significant factor in the storage environment. Conifer seeds are dried to below 10 percent moisture content (fresh weight basis) for long term storage. Optimal moisture content is between five and nine percent; moisture levels four percent or lower may lead to over-drying during storage and deterioration, especially for seeds of sub-orthodox species (Table 5.8).

Table 5.8 Moisture content thresholds & potential effects on stored seeds

Moisture %	Effects
>30%	Germination begins
18-20%	Overheating from respiration
10-18%	Seed fungi become active
>9%	Insect activity occurs
5-9%	Best range for sealed storage
<5%	Desiccation damage (possible in some species)

Source: USFS General Technical Report SO-106 September 1994

To avoid moisture uptake, proper storage in airtight and moisture-proof containers is essential. Properly sealed containers not only deter fluctuations in seed moisture content but also circumvent the need for costly humidity controls in the freezer unit. Fiberboard drums with plastic liners are effective for storage, as are heavy-weight polyethylene bags (six to eight mil is recommended) positioned inside a lidded standard size cardboard or plastic storage box. While a wall thickness of six mil or greater is an effective moisture barrier, a single bag may be pierced or torn whereas doubling two four mil bags is less likely to be compromised. This extra precaution provides better maintenance of seed moisture content over long periods and minimizes the effect of a freezer malfunction. If stored seeds are exposed to ambient conditions, either through distribution or sampling activities, they may gain or lose moisture to the atmosphere depending on the humidity level. Seeds stored for long periods should be retested for moisture content at infrequent intervals to be certain seed moisture levels are maintained in the acceptable range.

Conifer seeds retain viability for longer periods when storage temperatures are very low. Seed metabolic rates are minimized at low temperatures well below freezing; temperatures above minus 10^{o}C may allow resumption of respiration. The standard temperature recommendation for successful storage of orthodox seeds is minus 18^{o}C, assuming seed moisture content is in the acceptable range of five to nine percent.

<u>The reliability of the storage unit and the equipment used is of paramount importance</u>. The storage unit must have a reliable and dedicated power source plus safety alarms and a back-up generator in the event of malfunction or power failure. Placement of the storage unit inside a building will increase security and help to deter vandalism (fig. 5.53). Any controls on the outside of the building should be appropriately enclosed to prevent manipulation by unauthorized persons (fig. 5.55). Temperature controls and freezer management should be handled by knowledgeable and authorized personnel only (fig. 5.54).

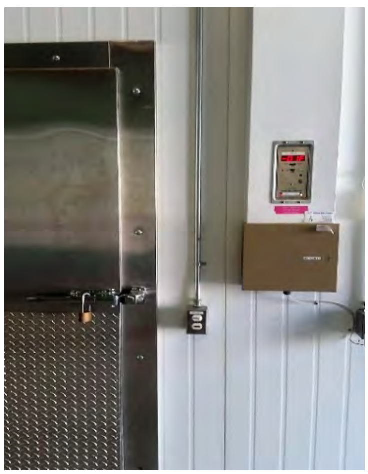

Figure 5.52 (left) Enclosed walk-in freezer at the L. A. Moran Reforestation Center, Davis. **Figure 5.53** (center) Freezer temperature control panel. **Figure 5.54** (right) Secured condenser units for walk-in freezer are protected from the elements.

The sealed storage boxes (above left) are light-weight, unbreakable, and maximize use of shelf space. Each box has a capacity of 15 to 25 pounds of seed depending on the species being stored; fiber drums can store 35 to 50 pounds per drum. Shelf systems must be sturdy and designed with seismic safety in mind.

All labeling must be clear and detailed; legible tags are located on the inside and outside of each bag with duplicate labeling affixed to the outside of the container. It is recommended that stacking of containers vertically be avoided to minimize the risk of crushing seed in the lowermost layers. Also, repeated opening and re-sealing of containers must be avoided to minimize moisture fluctuations. The storage location of an individual seed lot is recorded on its corresponding seed lot history form and in an electronic database.

Step 8 – Inventory Management

Records

It is essential to maintain meticulous records and compile a seed lot database to ensure the integrity of stored seed and associated source information. This is the data on which future collection planning and seed deployment decisions will be based. The preceding text has addressed the pertinent cone collection specifics recorded on the official Report of Collection (FM 44) and the importance of conscientious labeling throughout the collection, processing and storage phases. Critical seed quality information about individual seed lots may be assembled from the initial cone and seed assessment notes, extractory notes, preliminary and final x-rays and observations made during the germination testing process, all of which are contained in the permanent record.

A Seed Lot History (tracking) form is initiated upon delivery to the seed lab. This permanent record contains the source information from the Report of Collection and follows the seed lot through analysis, germination testing, repeat testing when appropriate, storage, inventory and distribution (fig. 5.55). If two or more seed lots are combined for any reason, all due diligence is necessary to make appropriate notations on records for each lot for tracking purposes. It is important to mix the combined seed lots thoroughly to maintain homogeneity.

SEED LOT HISTORY

SPECIES CODE	ZONE.ELEVATION	LOT NUMBER	SOURCE LAT: LONG:	CONE YEAR
PIPO	524.40	6076	T. 23N R. 4E SEC. 25, 26 CO. BUTTE	1994

NO. BU CONES	LBS. CLEAN SEED	LBS. C.S/B.C	INITIAL ASSESSMENT	PURITY%	SEED/LB.	MOISTURE %
50	52.7	1.05	Good X Fair__ Poor__ %Filled 84%	99.9%	9800	7.8%

X-RAY % FILLED 96%
GERMINATION RECORD

REBATE % ______
REBATE TO: none

STORAGE LOCATION 2 –B-3-2,~~5-9~~ ___ ___ ___ ___

DATE	PRE-TREATMENT	1st week	2nd week	3rd week	4th week	Final %	INVENTORY DISTRIBUTION	DATE	AMT USED	BALANCE
3/95	24 hr., no chill	0	3	12	146	40%	m/c, purity, s/lb., x-ray, 2 germs	1/17/95		52.76
3/95	24 hr., 6 wk. chill	10	318	63	0	97%	Magalia sow spring '95	1/17/95	4.2	48.5
8/96	24 hr., 6 wk. chill	9	326	54	0	97%	Davis sow '96	1/2/96	1.2	47.3
3/01	same	15	302	71	1	97%	Magalia sow '97	1/15/97	4.5	42.8
6/06	same	3	315	64	3	96%	Davis sow '98	12/30/97	1.2	41.6
8/11	24 hr., 6wk. chill	5	293	61	19	94%	Magalia sow '01, germ sample	1/15/01	4.0	37.6
4/14	24 hr., 6 wk. chill	5	289	62	24	95%	Davis sow '02	1/3/02	1.1	36.5
							Seed order # 02-17s	12/15/02	2.5	34.0
							Magalia sow '04	1/15/04	3.0	31.0
							Germ sample	5/3/06	0.1	30.9
							Magalia sow '08	1/12/08	2.6	28.3
							Seed order # 08-03s	11/29/08	1.4	26.9
							Germ sample	6/29/11	0.1	26.8
							Seed order # 14-32s, germ sample	2/28/14	2.1	24.7

Figure 5.55 Sample Seed Lot History form

Germination Retest Schedule

Ideally, operational seed lots are retested every three to five years to confirm germination percent or to identify potential loss in seed quality or vigor over time. Seed quality must be monitored at regular intervals because there is so much variation in quality between species and among individual seed lots and the particulars in which they were collected, processed and stored. An effective retest schedule is easily maintained by consulting the germination record in the master database. If germination loss has occurred, even under proper freezer storage conditions, the cause can generally be attributed to immature seed, poor seed quality, or deterioration due to harmful pathogens or advanced age.

When initial seed quality is high, seeds tend to store for extended periods and retain high quality status for much longer than seeds with low initial quality. This is especially true for incense cedar seeds. Incense cedar falls into the sub-orthodox category for seed storage behavior and typically declines more rapidly than hard-coated seeds. However if initial germination is high (more than 75 percent), loss is held to 10 to 20 percent or less over five to seven years and is still acceptable for the species. Alternatively, if initial germination percent is below 55 percent, then germination decline is generally much greater (20 to 40 percent) over a shorter period, usually three years or less.

Replacement Considerations

A germination retest may eventually indicate a drop in vigor whether germination capacity remains constant or has similarly declined. The speed of peak germination in a test may slow over time when compared to a previous result and is often the first expression of a decline in vigor. Vigor will decline in advance of viability. When both vigor and viability have waned and a subsequent test confirms the loss at 15 to 20 percent below the initial germination result for that seed lot, it is common practice to consider replacing the seed lot. As previously discussed, minimum germination standards vary by species and by collection region. If a seed lot declines to the minimum germination standard or lower for that species and its source is the northern or central Sierra where good cone crops are generally more frequent, the expectation is high that an opportunity to replace the failing seed lot will likely occur within the next local periodicity cycle. If the seed source is coastal, inland coastal, or in Southern California, where cone crops tend to be more erratic or lower quality, replacement may not be possible even if the germination is below standard. Without firm guidelines, the seed manager must thoroughly familiarize him/herself with the intricacies involved in sound seed replacement factors and strategies for many different species. Species such as pine and Douglas-fir may store for decades but other species including redwood, the true firs and incense cedar may require more frequent monitoring and plans to update the supply more often.

One must plan for sufficient inventory of viable seed to meet the projected need for a given planning period and for the myriad environmental challenges facing forest restoration professionals today including adapting to a changing climate, unforeseen events of uncontrolled fire, and massive die-off from elevated insect populations. The principal goals are to plan for the sometimes long intervals between good seed crops and to increase the odds for successful reforestation by obtaining the best seeds and storing them under optimal conditions intended to retain highest viability.

There is good reason to be as efficient as possible in this endeavor:

- Short supply of seeds
- Higher costs associated with collections (especially improved seed)
- Perceived increase in periodicity (number of years between bountiful cone crops)
- Increase in climate unknowns and unforeseen catastrophic events

Tree Improvement

The science and practice of forest genetics in California involves the selection of superior tree candidates, the establishment of clone banks, progeny test sites and seed production orchards, and the limited use of vegetative propagules. Tree improvement programs are designed to not only achieve sustained levels of improved volume growth and yield but also enhance the quality and broad adaptability of tree populations (Kitzmiller 1976). After a robust expansion in tree improvement activities through the 1980s, there was a rapid decline in state and federally funded tree improvement programs beginning in the early 1990s. This decline was primarily due to severe budget cuts plus the advent of shifting public views about harvest on public lands and greater emphasis on protecting old growth forests and habitat for endangered species. Opportunities for deploying improved stock were greatly reduced (Wheeler, et al. 2015). At this writing, state and federal participation still exists through tree improvement cooperatives but funding support remains low. For these agencies, the majority of forest tree seed collections are focused largely on collecting and utilizing local seed from the full range of commercially managed conifer species.

In the private sector, however, interest in faster growing, more productive forests continued and steered the desire to create forests of improved stock. This was accomplished mainly through the establishment of cooperatives which allow for sharing the considerable costs and benefits of such programs. Tree improvement associations in Northern California have active programs in the most productive sub-regions for four species: ponderosa pine and white fir in the Sierra, Douglas-fir on northern forests and sugar pine throughout the state for resistance to white pine blister rust, *Cronartium ribicola*. It is estimated that greater than sixty percent of reforestation plantings on private industrial forest lands in California are derived from such seed collections.

Genetic Quality of Seeds and Propagules

Tom Blush, USFS Geneticist

Genetic considerations should play a part in all forest regeneration efforts, whether they be natural or artificial, low or high management intensity. Stock selection for reforestation begins with a careful evaluation of the intended genetic constitution of the new forest. With the exception of vegetation propagules used for some coastal redwoods, the genetic considerations for most reforestation in California is addressed by collecting and utilizing quality seed from the region where the new seedlings will be planted. The high level of environmental site variability combined with the numerous commercial species that coexist on most sites has led to a much greater dependence on collecting seeds from local trees rather than region wide tree improvement programs. Most organizations managing forests are also involved in tree improvement programs for their key species of interest. These tree improvement programs follow a recurrent selection strategy where promising individuals are selected, bred, and tested over multiple generations (Wright 1976; Zobel and Talbert 1984; White, Adams, and Neale 2007). Offspring of the best individuals are deployed to the forest. Reforestation strategies can range from natural regeneration relying on sprouting or seed fall from residual stands to clonal propagation and deployment of elite varietals.

Natural Stands

Regeneration from natural stands and plantations represents the least-intensive management intensity of the genetic composition of the new forest. Foresters relying on regeneration from natural stands by seed collection, seed fall or by sprouting from residual trees would not rely on a tree improvement program for the species of interest. The genetic composition of the new forest would be determined by the genetic legacy available on the land. When relying on seed collection or regeneration from natural stands, the forester has considerable latitude and the obligation to control the genetic composition of the new forest to accomplish the long term reforestation goals. Traditional seed tree and shelterwood harvesting systems are intended to provide the manager with the opportunity to leave phenotypically desirable trees on the site as parents of the next generation. In California, appropriate seed collection and management depends to a large degree on collection of viable seeds by CAL FIRE and the USDA Forest Service. Restoration of disturbed ecosystems, a consequence of wildfire, insect infestation or storm damage, for instance, can also be achieved by regeneration from the residual stand. In this situation, foresters should carefully evaluate the potential of the residual forest to provide the necessary levels of genetic quality and diversity to achieve a desirable outcome. Restoration of disturbed ecosystems may require supplementing the genetic legacy of the site with reforestation stock from other sources deemed to be adapted to the site.

Seed Production Areas

Seed Production Areas (SPAs) are established by converting high-quality natural stands, plantations, or genetic evaluation tests to stands intensively managed for seed production (White, Adams, and Neale 2007). For species or seed zones without a tree improvement program, natural stands or plantations can be converted to SPAs with a well-planned and meticulous thinning operation. Prior to thinning, a careful marking operation should be done, attempting to leave only the fastest-growing, well-formed and disease-free trees. Plantations should not be converted to SPAs without verifying that the seed source of the planted trees is documented and preferably of local or near-local origin.

Converting genetic evaluation tests to SPAs has the potential to generate higher levels of genetic gain and diversity than conversion of natural stands or plantations to SPAs. Genetic evaluation plantations, such as progeny tests, are a component of a tree improvement program. The test plantation being converted to an SPA, as well as replicate test plantations, have usually been intensively measured for the desirable traits intended to be selected for in the tree improvement program. Analyses of these data are used to guide thinning and rogueing of the test plantation *to convert it to an SPA. In most cases, leave trees should have performed at least above the mean of the test population or some other quantitative benchmark.*

Open-pollinated Seed Orchards

Most tree improvement programs rely on open-pollinated seed orchards as their seed production populations (Zobel and McElwee 1964; Faulkner 1975; Simpson and Smith 1988). Seed orchards have several advantages as seed production populations. They can be located and managed specifically for seed production. Location is one of the most important factors in their success. Location should be carefully considered prior to establishing a new seed orchard. Many organizations have established seed orchards in administratively convenient locations, often near job sites on land that happens to be available, and have regretted this decision in the long run. Seed orchards should be located:

- *on land that is fertile and amenable to operability by farm machinery and aerial lifts,*
- *in climatically favorable zones for seed production, preferably isolated from wild stands or plantations of the same species,*
- *where management practices such as fertilization, irrigation, pest control, flower stimulation and crown management can be implemented to enhance seed production.*

The genetic quality of seed orchard seed is often neglected by managers in their drive to achieve high productivity. Seed orchards containing parents with high breeding values have the potential to produce high quality seed. This potential is realized when several biological assumptions essential for achieving genetic efficiency in seed orchards are met:

- *isolation from non-orchard pollen sources,*
- *balanced production of female and male flowers among the parents,*
- *flowering synchronization,*
- *random mating with equal compatibility for all crosses,*
- *minimal self-fertilization (Woessner and Franklin 1973).*

A seed orchard meeting all of these assumptions is said to be panmictic. But panmixia is rarely achieved. A manager striving to produce seed crops that reflect the potential genetic gain of the seed orchard population must identify deviations from these assumptions and correct or compensate for them (Hodge and White 1993).

Family Forestry

Erosion of genetic gain from open-pollinated seed orchards can be offset or overcome by managing the seed orchard to produce propagules with a defined family structure. Open-pollinated seed orchards are seldom panmictic, often deviating considerably from the seed orchard assumptions listed above. Although panmixia may promote a higher level of genetic diversity from the seed orchard crop, managers may decide to sacrifice some diversity for increased genetic gain by favoring families known to perform best for the traits of interest (Lindgren and Matheson 1986; Lindgren and El-Kassaby 1989; Kang, Lindgren, and Mullin 2001).

Open-pollinated families*. Parents in the seed orchard known to be especially desirable for a trait or traits of interest are identified. Seed is collected and processed from these parents. Depending on the variation among seed orchard parents and the selection intensity of the parents chosen for seed collection, considerable genetic gain can be realized in the planted forest using this simple and inexpensive management practice. Many variations of this strategy are possible. For instance, seed can be collected from a subset of top-quality "blue ribbon" seed orchard parents and mixed. The principle disadvantage of open-pollinated family deployment is that the pollen parent is uncontrolled (Adams and Tosh 1998). Many unknown pollen parents are represented in each open-pollinated family, often originating from lower quality parents located within the seed orchard or from "contaminants" from outside wild stands or plantations.*

***Full-sib families**. Both the maternal and paternal parent is known in a full-sib family. Producing and planting full-sib families has the potential to dramatically increase realized genetic gain in the new forest (Adams and Tosh 1998). In most forest tree species that are wind pollinated, full-sib seedlots are produced by controlled pollination. Unreceptive female flowers are isolated with pollination bags and pollen is injected into the bag when the isolated flowers become receptive. The pollination bags are removed when the flowers are past receptivity and the developing seeds allowed to mature. Controlled pollination, done in the breeding population, is a laborious and expensive process because the purity of crosses generated for genetic testing is of paramount concern. In the seed orchard, large quantities of full-sib seed can be produced by controlled mass pollination. Controlled mass pollination (CMP) employs the techniques of traditional controlled pollination scaled up to a production process (Carson 1986; Bramlett et al. 1993; Bridgwater et al. 1998). Large quantities of pollen are collected, processed, and stored for immediate use or for use in subsequent pollination seasons. Inexpensive paper pollination bags are rapidly installed and pollination is accomplished using automated systems. CMP can be done cost effectively on a large scale because it is not necessary to achieve absolute purity in the full-sib seedlots destined for outplanting. Full-sib seedlots of, say, 80% purity are acceptable for outplanting. Full-sib families generated by CMP are usually deployed to the field as single-family blocks. This gives the silviculturist greater control over the stand. Family block plantings can be observed and managed as an entity throughout the rotation (Adams and Tosh 1998). Organizations committed to establishing a fine-grained pattern of genetic diversity across the landscape can mix a number of full-sib families for outplanting. An intimate mixture of individuals from comparable families can probably achieve levels of realized genetic gain on a par with single-family block plantings.*

An organization practicing family forestry must commit itself to a durable system of stand record keeping that documents the genetic composition of the stand, and to complete harvesting of single- or mixed-family blocks at the end of the rotation. Seed collection from, or regeneration cuts (i.e. seed tree and shelterwood systems) applied to family blocks should not be attempted. The seed parents resulting from this would be related, and the subsequent stand established from this residual population would suffer from the deleterious effects resulting from inbreeding depression in the progeny that establish the new forest.

Varietal Forestry

Cloning of highly desirable individual genotypes is the ultimate means of capturing all of the gains generated in a tree improvement program (Ahuja and Libby 1993a, 1993b). The principal weakness of relying on seed as the delivery vehicle for genetic gain is the genetic recombination process that occurs after pollination and fertilization. Recombination tends to break up or disassociate combinations of genes that work together in an additive or synergistic fashion to produce a desirable trait or combination of traits. Cloning, theoretically, offers the forester the ability to capture that one-in-a-million individual identified during the testing phase of the breeding program and bulk it up ad infinitum. In most forest tree species, however, cloning is technically very challenging. Deployment of varietals across the landscape also presents many challenging social and biological considerations related to genetic diversity that the responsible forest manager must address. In forest trees, varietals are typically generated by vegetative propagation via rooting of cuttings, and the tissue culture techniques of organogenesis and somatic embryogenesis.

***Rooted cuttings**. Cloning by rooting of cuttings is a well-established process that has been practiced by horticulturists for centuries. For some species, such as those in the genus Populus, it is relatively easy to accomplish. In many conifer species, however, rooting of cuttings is technically demanding, inefficient, and costly. Few forest tree species lend themselves well to mass production of varietals from rooted cuttings. An important consideration in vegetative propagation in general and rooted cuttings in particular is maintaining juvenility in the stock plants. Rootability falls off rapidly as the stock plant matures. Rooted cuttings derived from more-mature stock plants may also grow slower and exhibit form traits more typical of mature plants. The most common means of maintaining juvenility in the stock plants is to cut them back or hedge them yearly and serially repropagate the stock plants as they become decadent. Maintaining juvenility, or at least slowing maturation is essential.*

Restoring mature individuals to a juvenile state does not appear to be feasible with current technology. Organizations contemplating mass production of varietals by rooted cuttings should employ an experienced horticulturist and must invest in the greenhouse and nursery technology required for success.

***Organogenesis**. Organogenesis is the tissue culture process of differentiating plant organs such as stems, leaves and roots from undifferentiated cells and tissues (Ahuja and Libby 1993a, 1993b). This tissue culture technique, applied to forest trees, is technically very demanding. It requires laboratory personnel and facilities to execute the tissue culture phases of the process. Organogenesis has been accomplished in numerous tree species, but only a few organizations have devoted the resources necessary for establishing a mass-production operation. The process requires, first, inducing shoot production and proliferation from callus tissue. These shoots are then harvested and induced to form roots. Timing and application of specific media formulations in a highly controlled, sterile environment are critical to success. Somaclonal variation, genetic changes induced by the tissue culture process, are a problem with organogenesis and must be carefully screened for. Mass production of varietals via organogenesis has limited potential in forest trees. It may be most useful in some hardwood species and as an avenue to facilitate genetic transformation approaches used by molecular geneticists.*

***Somatic embryogenesis**. Somatic embryogenesis (SE) is a promising tissue culture technology for cloning conifers by which somatic cells, usually immature just-fertilized embryonic tissue, is induced to proliferate and then to differentiate somatic embryos in a tissue culture system (Ahuja and Libby 1993a, 1993b). Like organogenesis, it is technically demanding and requires considerable expertise and facilities to accomplish. Unlike organogenesis, SE produces intact embryonic plantlets ready to germinate and grow. This makes it amenable to artificial seed technology. The starting material for SE is usually generated by controlled pollination, generating elite full-sib crosses. SE has, so far, proven to be highly genotype-specific in that the efficiency of the process varies widely depending on the female and male parents comprising the cross, the individuals within a cross and, often, the direction (female ↔ male) that the cross was made. Because SE is a tissue culture process, it also has the potential to integrate with genetic transformation technologies.*

Varietals can be mass produced by combining rooted cutting and tissue culture approaches. Tissue culture techniques can be used to establish lines, or clones, and the moderate number of propagules generated from the tissue culture process are then used to establish cutting orchards from which rooted cuttings can be mass produced. This capitalizes on the ability to cryopreserve tissue culture lines, thus indefinitely preserving and halting maturation in the donor line. And it takes advantage of rooted cutting technology to bulk up and mass produce cuttings in a less technically demanding greenhouse or nursery environment.

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References

Aitken, S. N., Bemmels, J. B. 2015. Time to get moving: assisted gene flow of trees. Evolutionary Applications. 9:271-290.

Barbour, M. G., Evens, J. M., Keeler-Wolf, T., Sawyer, J. O. 2016. California's Botanical Landscapes, A Pictorial View of the State's Vegetation. California Native Plant Society.

Barr, B. R., Koopman, M. E., Williams, C. D., Vynne, S. J., Hamilton, R., Doppelt, B. 2010. Preparing for Climate Change in the Klamath Basin. University of Oregon Climate Leadership Initiative and National Center for Conservation and Science Policy.

Bewley, J. D., Black, M. 1994. Seed physiology of development and germination. 2nd Ed. Plenum Press. New York.

Bonner, F. T., Karrfalt, R. P., et al. 2008. The Woody Plant Seed Manual. USDA Forest Service Ag Handbook 727.

Bonner, F. T., Vozzo, J. A., Elam, W. W., Land Jr., S. B. 1994. Tree Seed Technology Training Course. USDA Forest Service. General Technical Report SO-106.

Bruggink, H. 2012. X-ray based seed analysis and sorting. ISTA. (Incotec) seminar, webinar.

Chmura, D. J., Anderson, P. D., Howe, G. T., Harrington, C. A., Halofsky, J. E., Peterson D. L., Shaw, D. C., St. Clair, J. B. 2011. Forest responses to climate change in the Northwest US: Ecophysiological foundations for adaptive management. Forest Ecology and Management. 261:1121-1142.

Cleary, B. D., Greaves, R. D., Hermann, R.K. 1982. Regenerating Oregon's Forests. OSU. Corvallis, Oregon.

Cram, M. M., Fraedrich, S. W. 2009. Seed diseases and seedborne pathogens of North America. Tree Planter's Notes. Vol 53 No 2:35-40.

Edwards, D. G. W. 1981. Collection, processing, testing and storage of true fir seeds – A review. Presented at Cone Collection and Seed Processing workshop. OSU, July, 1983.

Eis, S., Craigdallie, D. 1981. Reproduction of Conifers. Canadian Forestry Service. BC.

Eremko, R. D., Edwards, D. G. W., Wallinger, D. 1989. A Guide to Collecting Cones of BC conifers. FRDA Report 055. BC.

Erickson, V., Aubry, C., Berrang, P., Blush, T., Bower, A., Crane, B., DeSpain, T., Gwaze, D., Hamlin, J., Horning, M., Johnson, R., Mahalovich, M., Maldonado, M., Sniezko, R., St. Clair, B. 2012. Genetic Resource Management and Climate Change: Genetic Options for Adapting National Forests to Climate Change. Washington, DC: USDA Forest Service, Forest Management.

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.

Franklin, E. C. 1970. Survey of mutant forms and inbreeding depression in species in the family Pinaceae. USDA Forest Research Paper SC-61. South Forest and Range Experimental Station, LA.

Furniss,R. L., Carolin, V. M. 1977. Western Forest Insects. US Forest Service. M.P. 1339.

Griffin, J. R., Critchfield, W. B. 1972. The Distribution of forest trees in California. USDA Forest Service Research Paper PSW-82.

Guinon, M. 1992. Promoting gene conservation through seed and plant procurement. Proceedings, Western Forest Nursery Association Pp 38-45.

Harrington CA, St. Clair B. 2017. The Douglas-fir seed-source movement trial yields early results. Western Forester September/October:22-24.

Jepson, W. L. 1993. The Jepson Manual Higher Plants of California. University of California Press. Berkeley, CA.

Kitzmiller, J. H. 2009. North Sierra Tree Improvement Association (NSTIA) 30-Year Anniversary – The Ponderosa Pine Program. Unpublished.

Kitzmiller, J. H. 1990. Managing genetic diversity in a tree improvement program. Forest Ecology and Management 35:131-149.

Kitzmiller, J. H. 1976. Tree Improvement Master Plan for the California Region. USDA Forest Service.

Kolotelo, D. 1997. Anatomy & Morphology of Conifer Tree Seed. Forest Nursery Technical Series 1.1. BC Ministry of Forests.

Kolotelo, D., Van Steenis, E., Peterson, M., Bennett, R., Trotter, D., Dennis, J. 2001. Seed Handling Guidebook. BC Ministry of Forests.

Leadem, C. L., Eremko, R. D., Davis, I. H. 1990. Regenerating British Columbia's Forests. Ch. 15:193-205.

Leadum, C. L. 2000. Advances and challenges in seed biology. Seed and Seedling Technology. Conference Proceedings, OSU and Western Forest & Conservation Association.

Ledig, T., Kitzmiller, J. H. 1992. Genetic strategies for reforestation in the face of global climate change. Forest Ecology and Management 50:153-169.

Lippitt, L., Fidelibus, M. W., Bainbridge, D. A. 1994. Native seed collection, processing and storage for revegetation projects in the Western US. Restoration Ecology Vol 2 No 2:120-131.

Lippitt, L. 1998. Nursery Program Analysis, CA Department of Forestry & Fire Protection. Unpublished.

Millar, C. I. 2013. The Role of Assisted Migration in Climate Adaptation Planning: When and Where to Employ it. Pacific Southwest Research Station, USDA Forest Service, Albany, CA. Presentation Slides (.pdf).

Millar, C. I., Stephenson, N. L., Stephens, S. T. 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecological Applications 17: 2145-2151.

O'Neill G, Wang T, Ukrainetz N, Charleson L, McCauley L, Yanchuk A, Zedel S. 2017. A proposed climate-based seed transfer system for British Columbia in Program FS, ed. Victoria, B.C., Canada: Province of British Columbia.

Rehfeldt, G. E., Jaquish, B. C., Saenz-Romero, C., Joyce, D. G., Leites, L. P., St Clair, B. J., Lopez-Upton, J. 2014. Comparative genetic responses to climate in the varieties of Pinus ponderosa and Pseudotsuga menziesii: reforestation. Forest Ecology and Management. 324: 147-157.

Rosenthal, Anne M; Millar, Constance I. 2003. Climate Change: Detecting Climate's Imprint on California Forests. Science Perspective PSW-SP-001. Albany, CA: USDA Forest Service, PSW Research Station. 6p.

Ruth, D. S. 1980. A guide to insect pests in Douglas-fir seed orchards. 1BC Canadian Forestry Service. BC-X-204.

Sawyer, J. O., Keeler-Wolf, T., Evens, J. M. 2009. A Manual of California Vegetation. CNPS Press Sacramento. 2nd Edition.

Schubert, G. H., Adams, R. S. 1971. Reforestation Practices for conifers in California. State of California, Division of Forestry.

Silen, R. 1978. Genetics of Douglas-fir. USDA Forest Service Research Paper WO-35.

Smith, R. E. 1980. Ecology and Field Biology. Harper & Row, NY. 3rd Edition.

St. Clair B, Howe G. 2017. Building on a century of forest genetics research. Westen Forester September/October:16-17.

St Clair, Brad. 2013. Landscape Variation in Adaptation and Implications for Managing Future Climates. Pacific Northwest Research Station, USDA Forest Service, Corvallis, OR. Presentation Slides (.pdf).

Sudworth, G. B. 1967. Forest Trees of the Pacific Slope. Dover Publications, Inc. N.Y.

Sutherland, J. R., Miller, T., Quinard, R.S. 1987. Cone and seed diseases of North American conifers. North American Forestry Commission (NAFC). Publication No 1. BC.

Tekiela, S. 2003. Birds of California field guide. Adventure Publications, Inc. MN.

Tkacz, B., Dillard, D., et al. 2010. National Roadmap for Responding to Climate Change. USDA Forest Service.

Wheeler, N.C., Steiner, K.C., Schlarbaum, S.E., Neale, D.B. 2015. "The Evolution of Forest Genetics and Tree Improvement in the United States", Journal of Forestry, Vol. 113, Issue 5, 1 September 2015, Pages 500-510.

Williams, Mary I., Dumroese, R. Kasten. 2014. Role of Climate Change in Reforestation & Nursery Practices. Western Forester. 59(1): 11-13.

Wood, D. L., Koerber, T. W. Scharpf, R. F., Storer, A.J. 2003. Pests of the native California conifers. University of California Press, Berkeley and Los Angeles, California.

Also:

California's Forests and Rangelands: 2017 Assessment. Chapter 7: Climate Change. Chapter 10: Wildlife Habitat. CAL FIRE website: http://frap.fire.ca.gov/assessment2017/index

Diseases of Pacific Coast Conifers. 1978. USDA Forest Service Ag Handbook #521.

California Forest Insects & Disease Training manual. 2008. USDA Forest Service Region 5 and CA Department of Forestry & Fire Protection.

International Rules for Seed Testing, Vol. 2016. Switzerland

Association of Official Seed Analysts Seed Testing Rules, 2015. Vigor 2002; Moisture Content 2007.

References for: Genetic Quality of Seeds and Propagules

Adams, G. W. and K. J. Tosh. 1998. The status and potential of using controlled parentage in operational reforestation in New Brunswick. The Forestry Chronicle 74(2):190-194.

Ahuja, M. R. and W. J. Libby (eds.). 1993a. Clonal forestry. 1. Genetics and biotechnology. Berlin, Heidelberg: Springer-Verlag.

Ahuja, M. R. and W. J. Libby (eds.). 1993b. Clonal forestry. 2. Conservation and application. Berlin, Heidelberg: Springer-Verlag, Berlin.

Bramlett, D. L., G. R. Askew, T. D. Blush, F. E. Bridgwater and J. B. Jett. 1993. Advances in pollen management. USDA Forest Service, Agriculture Handbook 698.

Bridgwater, F. E., D. L. Bramlett, T. D. Byram and W. J. Lowe. 1998. Controlled mass pollination in loblolly pine to increase genetic gains. The Forestry Chronicle 74(2):185-189.

Buck JM, Adams RS, Cone J, Conkle MT, Libby WJ, Eden CJ, Knight MJ. 1970. California Tree Seed Zones. U.S.D.A. Forest Service and California Division of Forestry. San Francisco, CA

Carson, M. J. 1986. Control-pollinated seed orchards of best general combiners – a new strategy for radiata pine improvement. pp. 144-149 *in* T. A. Williams and G. Wratt (eds.). Proceedings of the DSIR Plant Breeding Symposium, Lincoln. Agronomy Society of New Zealand, Special Publication 5.

Faulkner, R. (ed.) 1975. Seed orchards. Forestry Commission Bulletin No. 54. London: Her Majesty's Stationery Office.

Fowells, H. A. 1946. Forest seed collection zones in California. U.S.D.A. Forest Service and California Division of Forestry Note 51. San Francisco, CA.

Franklin, E. C. (ed.). 1981. Pollen management handbook. USDA Forest Service, Agriculture Handbook Number 587.

Hodge, G. R. and T. L. White. 1993. Advanced-generation wind-pollinated seed orchard design. New Forests 7:213-236.

Kang, K. S., D. Lindgren, and T. J. Mullin. 2001. Prediction of genetic gain and gene diversity in seed orhcard crops under alternative management strategies. Theoretical and Applied Genetics 103:1099-1107.

Lindgren, D. and Y. A. El-Kassaby. 1989. Genetic consequences of combining selective cone harvesting and genetic thinning in clonal seed orchards. Silvae Genetica 38(2):65-70.

Lindgren, D. and A. C. Matheson. 1986. An algorithm for increasing the genetic quality of seed from seed orchards by using the better clones in higher proportions. Silvae Genetica 35(5-6):173-177.

Matheson, A. C. and D. Lindgren. 1985. Gains from the clonal and clonal seed-orchard options compared for tree breeding programs. Theoretical and Applied Genetics 71:242-249.

Roy D.F. 1963. Instructions and codes for recording forest tree seed information in California. US Forest Service Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

Schubert GH. 1966. Major and local seed collection zones in California. US Forest Service Pacific Southwest Forest and Range Experiment Station, Berkeley, CA.

Simpson, J. D. and R. F. Smith. 1988. A manual for forest tree seed orchard management in the Maritimes. Information Report M-X-167. Canadian Forestry Service – Maritimes.

White, T. L., W. T. Adams, and D. B. Neale. 2007. Forest genetics. Oxfordshire UK and Cambridge, MA: CAB International.

Woessner, R. A., and E. C. Franklin. 1973. Continued reliance on wind-pollinated southern pine seed orchards – is it reasonable? Proc. 12th Southern Forest Tree Improvement Conference. pp. 64-73.

Wright, J. W. 1976. Introduction to forest genetics. New York: Academic Press.

Zobel, B. and R. L. McElwee. 1964. Seed orchards for the production of genetically improved seed. Silvae Genetica 13(1-2):1-56.

Zobel, B. and J. Talbert. 1984. Applied forest tree improvement. Prospect Heights IL: Waveland Press, Inc.

Glossary of Cone & Seed Handling Terms

- adaptation – characteristics that have evolved by natural selection over time that enable an organism to be successful (survive and reproduce) in a given environment
- bract - a modified leaf which extends underneath a seed bearing scale (DF, Shasta RF)
- case-hardened - inability of cone scales to flex caused by too rapid drying, insects or disease
- corrosion cavity – the cavity in the central portion of the megagametophyte that forms through cell breakdown. The embryo will grow into this cavity
- cotyledon - primary leaf of the embryo
- damping-off – the killing of a seedling by micro-organisms before emergence from the soil or the collapse of the hypocotyl and/or radicle immediately after emergence
- dead-filled seed – the complete deterioration of all seed contents
- dormancy - a physiological state in which a seed is capable of germination but does not
- embryo dormancy - conditions within the embryo

- embryo - rudimentary plant within a seed
- empty seed - a seed that is hollow, corky, pitchy or filled with larvae
- endosperm - female gametophyte. Correctly termed Megagametophyte in gymnosperms
- fertilization - fusion of the sperm nucleus w/ egg cell nucleus and doubling of chromosomes (for 1-yr species - this occurs in early summer; for 2-yr species - this occurs in spring of the 2^{nd} year)
- filled seed - a seed containing all tissues essential for germination and considered potentially viable
- frass – insect excrement found on or within cones; usually indicative of feeding activity/damage
- genetic “generalist” - species that show low genetic differentiation across a wide range of environmental gradients
- genetic “specialist” – species that exhibit strong genetic differentiation over small geographic and climate scales
- hypocotyl - embryonic stem below the cotyledons and directly above the radicle (primary root)
- imbibed – seeds that have become swollen and physiologically active due to uptake of water – this moisture must reach the embryo
- integument – the coat of an ovule which develops into the seed coat
- megagametophyte – storage tissue that provides nutrients to the developing embryo; also sometimes referred to as endosperm
- microclimate – The climate of small areas especially in regard to significant differences from the general climate of the region
- moisture content – for seed, is based on the proportion of moisture relative to the fresh weight of the seed and is usually presented as a percentage. M/C = fresh wt.- oven-dry wt. / fresh wt. x 100
- morphology – study of form and structure of an organism, especially their external form (size, color)
- orthodox – seeds that can be dried to low moisture content and stored for extended periods without losing viability

- peduncle – the stalk or stem of a cone
- phenotype - visual appearance of having desirable characteristics (genotype + environment)
- phenotypic plasticity – the ability of a genotype or a population to maintain high fitness across a range of environments by altering its phenotype
- periodicity - number of years between bountiful crops
- pollen cone - male reproductive structure - produces pollen grains
- pollination - transfer of pollen from male cone to female cone (in conifers-wind pollinated)
- poly-embryony – the formation of more than one embryo in a seed
- pre-conditioning - facilitating after-ripening in preparation for kilning +/or tumbling (racking & turning sacks)
- primordia - rudimentary structure at the earliest stages of development
- progeny - offspring of plants
- purity – seed lot characteristic describing the weight of pure seed in relation to the weight of seed + debris. A purity standard above 98% is necessary for nursery calculations
- radicle - primary root of the embryo
- recalcitrant – seeds that are resistant to drying and storing (must be fresh collected when available)
- scarification – degradation of the seed coat by mechanical abrasion, chemical or hot water treatment to increase water uptake and gas exchange
- seed - a matured ovule containing an embryo and megagametophyte, enclosed by a protective seed coat which is capable of developing into a plant under favorable conditions
- seed coat dormancy - impermeable to gas and moisture exchange
- seed cone - female reproductive structure - usually two seeds borne on each scale spirally arranged around a central axis
- seed lot - a quantity of cones or seed having uniformity of species, source, quality and year of collection
- seed source - location where the seeds were collected; seed zone and elevation (T, R, Sec and/or Lat/Long)
- seed zone - in Calif. arbitrary area designated on the basis of biogeographic and climate regions & latitude

- self-pollination – the transfer of pollen from the stamen to the stigma on the same plant (tree); aka “selfing”
- serotiny – pertaining to cones that remain closed on the tree for several months or years after maturity making them late in dispersing seeds
- stratification - pre-germination treatment of seeds to overcome dormancy and to promote rapid and uniform germination - synonymous with moist chilling
- superior tree – a phenotypically outstanding tree that has no visible undesirable characteristics and produces more cu ft. volume/yr. when compared to immediate even-aged neighbors. JK
- tolerance – the permitted deviation from a standard beyond which a germination test must be repeated
- viable - capable of germinating - <u>viable seeds are filled but not all filled seeds are viable</u>
- vigor – robustness of a seed lot; declines with age

Chapter 6: Seedlings

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Conifer Seedling Nurseries in California

Tree seedlings for reforestation projects need to survive and grow well without the additional care of irrigation and fertilization applied to trees planted for landscaping in California. For this reason, and the requirement for very low cost per seedling, reforestation seedlings are grown in nurseries specialized for the task. Reforestation nurseries offer a range of species and growing regimes because site, climate, and seedling conditions can affect seedling performance. Foresters can improve seedling success by choosing a target seedling with characteristics that match the seedling with the site where it will be planted (Dumroese et. al. 2016.) This chapter details how these factors affect the three major considerations that lead to the selection of target seedlings: choosing species and seed source, choosing stock type, and choosing a nursery. The goal is to obtain seedlings that live and grow vigorously when they are planted on a reforestation site. Note that this chapter describes how to evaluate nurseries, but does not detail seedling growing practices. For a detailed discussion about how seedlings are grown see The Container Tree Nursery Manual (Landis et al. 1994).

Choosing Species and Seed Source

When planning a reforestation project, one very important consideration is which species to plant within the project area. The species choice will have long-term effects on the productivity of the site and on the options available to the landowners and future generations of foresters who will manage the forest.

Historical Species Composition

A guiding factor for any decision regarding the species to plant is the original species composition of the pre-disturbance forest (before logging or fire), reflecting those species that performed well over the preceding decades. Although a general indication of which species are adapted to a given site can be determined from the previous species on the site (or those immediately adjacent), decades of fire suppression and logging may have significantly altered the original species composition. For example, a recent history of low fire occurrence will favor species that may grow fast but have high mortality rates from fires. Historical market preferences for certain species with higher harvested market value can also have major influences on the current mix of species by reducing the natural seed supply from trees harvested for their high historic market value for timber. Besides past management activities and fire incidence, a review of the long-term site conditions can provide additional information needed to determine the most suitable species composition that is naturally adapted to the site.

One must also consider the species composition by age class for the overall ownership compared to the long-term target of suitable species composition by age class. If a landowner manages primarily with uneven-aged silviculture, then the only opportunity to establish new age classes of relatively shade-intolerant Douglas-fir (DF) and ponderosa pine (PP) is through planting in conditions where the seedlings are not under heavy shade from overstory trees. If the overall forest ownership is lacking in young age classes of such desirable species, then when planting opportunities exist, shade intolerant species should be considered provided they are adapted to the site. New age classes of shade-tolerant species such as white fir (WF) and incense-cedar (IC) often do not need to be planted as they often will naturally reproduce and grow.

Site Conditions

Aspect, elevation, and soil type should also influence species choice. Reforestation units may have several different aspects and may therefore require different species distribution based on aspect. In replanting mixed species, planting the hardiest species at a higher rate on south-facing slopes or rocky soils will increase establishment success. On most California sites, the hardiest and least shade-tolerant species is PP. On north-facing slopes, relatively more shade-tolerant species such as DF or true fir species such as red fir (RF) or WF may be more successful. On harsh, north-facing slopes, if there is no evidence of PP in the original forest species mix, then it is likely not well suited to the site and should not be planted. Species that are highly sensitive to hot temperatures and sunscald should be planted in the most favorable microsites, using natural features that provide seedling protection from the harsh conditions. An example of a microsite is the north-east side of stumps, rocks, or large woody debris that will shade the seedling in the afternoon.

Elevation is another important consideration when assessing a site for the proper species mix. In general, interior low-elevation sites are dominated by PP. As elevation increases, the mix of other species also increases. Mid-elevation sites may have a higher percentage of IC, DF and SP in the species mix for interior California and high-elevation sites will shift to species that are adapted to high snow loads such as RF and WF. On eastside sites or high Sierra, Jeffrey pine (JP), PP, and SP may be appropriate at higher elevations (5500’-6500’) if seed adapted to high elevation is available.

Climatic Conditions

Precipitation and temperature are also important to consider when choosing the appropriate species to use on a site. For example, in areas with low annual rainfall and coarse soils, hardy species such as PP or JP would be a better fit than DF or true fir. Seasonal distribution of precipitation on the site is more important than the total annual precipitation in species choice as the ability to survive months of limited water availability is not consistent across species. In coastal areas, rainfall patterns and elevation are key factors in determining the range of coast redwood. In general, as distance from the ocean and elevation increase, the species mix transitions from redwood to DF. The coastal influence that produces fog and summer rain decreases inland and limits the ability of redwoods to survive.

Sites with large diurnal temperature fluctuations such as basins that have warm spring days and overnight inversion frost events may require well adapted species to avoid premature bud break and dieback of new growth. WF and DF are species that are difficult to establish in areas that have frequent inversion frost events after growth has initiated in the spring. It is important to assess the topography to identify possible locations where cold air drainage and temperature inversions could result in seedling mortality.

A consideration of all site conditions will provide guidance to appropriate species selection for any given site. For example: a 2500' elevation site with sandy soils and predominately south facing slopes would be a good candidate for PP. Another site at the same elevation, but with north facing slopes and loamy soils, would be best with a mix of species. Identifying where mixed species are most appropriate is an important component of a successful reforestation project.

Natural Range

The natural range of the species to plant should influence the choice of species in a reforestation project. If a planting site is near the edge of a species' range, the percent of that species should be decreased in the mix. For example, where the eastern range of DF meets the east side pine type, it would be prudent to plant DF in favorable aspects only and avoid areas that are naturally PP flats prone to spring frost.

Understanding a stand's succession history is also an important consideration when choosing species (Hessburg et al. 2005). Representative of this is a species that became the dominant species in a stand by growing in the shelter of a nurse crop. Higher elevation sites that are dominated by WF or RF may have originally been brush fields created by old burns that served as a nurse crop to protect the young firs from frost and sunscald. Reforesting this type of site with RF and WF may be difficult if the seedlings are to be planted in full sunlight conditions. It would be best to plant a species that is more tolerant of the severe conditions (i.e., PP) as a nurse crop for the fir even though it will not be a major component of the final stand. Another example is a DF stand that resulted from growing in the understory of oak. DF may need to be grown in a mix with other species to thrive on the same site. Finally, sites with a long history of single tree selection of the taller or more valuable trees may have changed significantly from the initial shade intolerant pine to more shade tolerant species such as white fir.

Forest Health

Long-term health of the future forest can be profoundly affected by the choice of species planted on the site. In general, it is best to avoid planting a high percentage of particular species in areas that are known to have diseases that cause mortality to that species. Creating a monoculture forest in an area that was historically a mixed species stand could result in failure from pests. Species diversity is the only way to ensure that a single pathogen or insect outbreak does not compromise the health of the stand or result in failure of the reforestation project.

High rates of diseases, such as black stain or “annosus” root rot disease, which are species-specific in an area would dictate planting a different species in that area (Hessburg et al. 1995). Annosus root rot has two distinct biological species with different host preferences. The P group attacks pine, cedar, and juniper while the S group attacks fir, hemlock, and giant sequoia. It is important to know which type of annosus is present on the site and plant seedlings that are not affected by that group of pathogen. [*Ch.11-Damage-Root Diseases*]

Choice of specific seed lots within a species can also have an effect on the likelihood of planting success. Planted SP seedlings, for example, should be from blister rust resistant (BRR) parent trees if such seed is available. Similarly, in areas where PP is known to have high levels of damage from gouty pitch midge, some or all of the seedlings should be from resistant parent trees or from alternate species that pitch midge doesn’t attack.

Seed Source

The source of the seed used for a reforestation project will have a lasting effect on the quality of the future forest. A properly sourced seedlot can have a dramatic effect on the future growth of the stand, the quality of the resulting forest products, and on the ability of the stand to resist insect and disease problems. The two basic types of seed available for reforestation projects are improved seed from seed orchards and seed that is collected from wild stands.

Improved seed produced through tree improvement associations is usually a clear first choice when selecting seed for a sowing order. This type of seed is distributed to members of the tree improvement associations but may be available to the general public through the LA Moran Reforestation Center’s state seed bank, commercial forest seed sellers or from one of the tree improvement association members. The choice of which improved lot to use is dependent on several factors. First, the forester may have to choose between using the oldest appropriate seed versus using the "best available" seed. The "best available" is the seed with highest germination percent that was produced after the final "rogueing" in the seed orchard. This choice may be driven by the seed bank management policies of the user. A second criteria is the weighted elevational average of the seed collected in any given year. Each year, the trees in the orchard from which seed is collected will vary and that will influence the average elevation of the resulting seed lot.

Wild collected seed has many more variables associated with it than does seed produced in cultivated seed orchards. Careful selection of trees with superior phenotypes, following the basic collection standards detailed in *Chapter 5 "Cones and Seed*", is a key factor in acquiring a seed lot that produces quality seedlings. In many cases, the quality of the seed lot depends on the experience of the forester choosing which trees to harvest cones from.

When considering lots for sowing orders at the nursery, the most basic requirement is to match the seed zone and the collection elevation of the reforestation site. The seed lot must also have a sufficient quantity of seed with a high enough germination percentage for the nursery to produce the requested number of seedlings. If there are many lots to choose from, then more factors can be considered to better match the seedling to the site. Collection data should show the number of trees harvested, the number of bushels per tree allowed to be harvested, and the extent of the area harvested. If the seed lot is produced from a collection of a few trees growing in close proximity to each other, the seed produced will have low genetic variability and should not be expected to perform well in a wide range of sites. The species may influence the consideration of this factor. Douglas fir (DF) is considered more of a genetic specialist that shows more sensitivity to elevational moves or movement out of its local range. Choosing lots that are from the general area to be reforested is very important with DF. Orchard collections of DF may not be as adaptable as local collected seed for areas that are on the edge of the DF range or from different climatic regions. In those circumstances, it is advisable to favor local seed lots over orchard lots or mix orchard seedlings with local sourced seedlings.

Collection data may include information on disease and insect resistance. An example is where the collecting forester noted in the cone collection data sheet that a ponderosa pine collection avoided trees with evidence of gouty pitch midge and western gall rust damage.

The age of the collection can be very important for some species. White fir, red fir and incense cedar have a relatively short storage life which may influence the choice of seed lots. Even if the seed germinates in older seed, the seedlings produced may fail to perform both in the nursery and after out-planting. The seed from these species also do not perform well if the cone harvest occurs before the cones are at full ripeness. Low germination rates and poor seedling growth must be considered or even expected when sowing these types of seed lots. Frequent collections to upgrade the quality of stored seed is advisable.

Working with the nursery is helpful when using the same seed lots over the course of many years. All seed lots have performance characteristics that are unique from other lots especially in wild collected, open pollinated lots. Some lots will show a deterioration in germination over time that the nursery will note. These lots should be avoided at sowing time unless there is no better alternative.

Choosing Stock Type

"Stock type" refers to the method that is used to produce the seedling, typically container or bareroot, and the range of choices within each of these two basic production methods. Currently, almost all of the seedlings planted in California are container seedlings. The key to making a successful stock type decision is relating stock type choices to seedling physiological and morphological conditions that are indicators of seedling quality.

Seedling Physiology

A successful reforestation seedling must be able to survive the conditions on the site and then rapidly grow roots and shoots when site conditions are favorable. This expectation means that each seedling must be in a proper physiological state when it leaves the nursery or the storage facility.

Physiological characteristics that contribute to the overall quality of the seedlings are (Haase 2008):

- root growth potential,
- dormancy,
- cold hardiness,
- plant moisture stress,
- nutrient status, and
- chlorophyll fluorescence

Unlike morphological characteristics such as height, stem diameter, and root: shoot ratio, most physiological attributes are difficult to measure and require some laboratory equipment.

Root Growth Potential

Root growth potential (RGP) is perhaps the most commonly used test to evaluate the physiological condition of forest seedlings. A simple non-quantitative version of an RGP test is a planting test. The planting test does not require specialized laboratory equipment and is one test for physiological conditions that is easily accomplished by nurseries and reforestation specialists. Seedlings are planted in a field plot or growing media in an easily accessible location. Sometime later, these seedlings are dug up and the root growth is observed. Nurseries can use this test to evaluate the health of seedlings at the time of packing and shipping. If the seedlings are stored at the nursery, seedlings can be evaluated when they are removed from storage and shipped. Field foresters can plant seedlings in a field plot to compare the performance of multiple seedlots and species, different stock types, and seedlings sourced from different nurseries. Drawbacks of this type of evaluation are that the results are usually not quantified, except if survival is an issue, and the results are typically not available until after the seedlings have been outplanted.

A more rigorous, quantifiable RGP test is conducted by planting a random sample of seedlings into an environment in the lab that is favorable for rapid root growth and systematically evaluating root growth after 3 to 4 weeks. A minimum sample size should be at least 25-30 seedlings and it is best if 60 randomly collected seedlings are tested. The sample collection time will depend on the purpose of the testing. For example, if the nursery is conducting the test to evaluate the seedlings' ability to produce roots, then the sample should be taken during packing. If the forester is interested in outplanting performance, taking the sample just before planting will quantify effects of lifting, transportation and handling. It is important to make the sample truly random by getting sample seedlings from different areas of the packing boxes and throughout the stored lot.

The RGP can provide an indication of the health of seedlings, but may not be a comprehensive indicator of seedling performance after outplanting because it is conducted under ideal conditions rather than conditions typically found on reforestation sites (Simpson and Ritchie 1997).

Dormancy

Dormancy is a period of inactivity of buds or other plant organs that may be imposed by unfavorable environmental conditions or may be the result of internal physiological conditions (Cleary et al. 1978). Common observable indicators that seedlings are becoming dormant include the development of terminal and lateral buds with mature bud scales (in species that form bud scales), stiffening of the stems as they become more woody, thickening and darkening of the foliage, and slowing of root growth. Evaluating dormancy is critically important for determining the best time period to pack and store seedlings, a time period often referred to as a "lifting window". Seedlings packed when they are not fully dormant do not store well and will not perform well when outplanted. Evaluating dormancy is particularly important for the fall planting decisions described below.

In container nurseries, some species may transition to dormancy in response to natural conditions. However, in most cases seedling dormancy is induced by increasing moisture and nutrient stress, by exposing seedlings to cold ambient temperatures, and/or by artificially shortening the day length (photoperiod). Successful dormancy induction protocols in the nursery typically include combinations of reduced fertilization (particularly nitrogen), increased moisture stress between irrigations to the point of wilting or near-wilting, and exposure to ambient conditions. After the onset of dormancy is apparent, stress levels are reduced until the seedlings become fully dormant.

Seedlings of many species may be induced to become dormant by artificially shortening the day length using “black out” equipment in the greenhouse. This reduction in photoperiod may be accompanied by some short-term reduction in nutrient levels, although high levels of nutrient and moisture stress are not needed. Seedlings produced using this method are often shorter, have larger stem diameters, have higher tissue nutrient levels, and have higher root: shoot ratios. Field performance of Douglas-fir planted on high stress sites in California has particularly benefitted from the proper application of “black-out” technology during seedling production.

In nurseries located in areas with cold winters, seedlings are typically in a state of deep dormancy from mid-November or early December through mid- February. Following a period of chilling with temperatures below 45°F, the dormancy will be released and the seedlings will resume growth when environmental conditions are favorable. Quantitative testing for identifying the end of dormancy is usually done with a bud break test. This test requires planting randomly selected samples in a greenhouse under favorable growing conditions. Visual indicators that dormancy has ended include root growth initiation and terminal bud swelling.

Dormancy is important when considering fall plant timing because the seedlings need to be metabolically active and capable of active root growth. Seedlings planted in late October or November where soils are cold will be unlikely to support root growth and are at risk of mortality if they are not covered with snow during the winter period. For spring planting, the deep dormancy period will be over when the seedlings are planted and they will be ready to grow when conditions become favorable.

Cold Hardiness

Cold hardiness is the level of a plant’s resistance to damage from cold temperature **(**Rose and Haase 2006). It is an indicator of the seedling’s physiological state and is commonly used in assessing forest seedling quality. It is important to remember that seedling cold hardiness is not the same as dormancy (Haase 2011a). Seedlings begin to develop cold hardiness in fall as seedlings become dormant but usually don’t achieve maximum hardiness until mid-winter, well after full dormancy. They often remain cold hardy even as dormancy levels begin to drop. Absolute hardiness varies greatly among species and ecotypes and is highly influenced by the climate of seed origin and by the nursery growing conditions.

Seedlings may be tested for hardiness before packing or during or after storage. One commonly used cold hardiness test is the “whole plant freeze test”, in which the entire plant is exposed to freezing temperatures and then evaluated for response (Linden 2002). Another is the freeze-induced electrolyte leakage test, which is used to test foliar and root samples (Landis et al. 2010). These tests are mainly used by nursery managers to establish lifting windows or to determine whether frost protection measures are necessary.

Plant Moisture Stress (PMS), Nutrient Status, and Chlorophyll Fluorescence

Plant moisture stress (PMS), nutrient status, and chlorophyll fluorescence levels are other physiological conditions that may influence seedling quality. PMS can be measured in the field using portable pressure chambers. Seedlings with very high PMS readings are unlikely to do well if outplanted. Nutrient status can be easily assessed by labs that specialize in tissue analysis. Seedlings with appropriate tissue levels of mineral nutrients, particularly tissue nitrogen, will perform better than seedlings where nutrients are either too high or too low. Measurements of chloropyll florescence (CF) are used to provide indications of seedling quality (Ritchie 2006.) The recent development of portable equipment to measure CF has made this test more accessible to foresters and nurseries. The *Container Tree Nursery Manual* (volume 7) is an excellent source of detailed information on these topics (Landis et al. 2010).

Seedling Morphology

The most common measurements used to assess seedling morphology are: seedling height, caliper, root system quality (fibrosity and mass) (Haase 2011b) and the ratio of shoot to root mass. Caliper is the seedling diameter measured just above the root collar and is often expressed in millimeters. The root:shoot ratio is the root weight divided by shoot weight, or the root volume divided by shoot volume (Rose and Haase 2006).

These measurements, particularly height and stem caliper, are the most common measure of seedling quality used by both nursery operators and reforestation specialists. Reforestation seedlings grown in the 1970s and early1980s were mostly bareroot and the influence of morphology on seedling survival and performance was well studied (Cleary et al. 1978). Survival is best predicted by caliper, while shoot growth tends to be more related to initial seedling height. With bareroot stock, when stem diameter increases above 5 mm, other morphological indicators become less important (Mexal and Landis 1990). In addition, bareroot seedlings with larger root volumes at the time of outplanting have greater subsequent growth and survival than bareroot seedlings with smaller root volumes (Rose et al. 1997).

Container seedling morphology is influenced by cell volume and growing density. In general, larger cells produce seedlings with larger root volumes and lower densities produce seedlings with larger stem diameters and increased lateral branching. Container stock quality attributes are similar to those of bareroot stock but container nurseries have greater control of height and diameter growth with the use of blackout and other cultural practices.

It is important for the reforestation specialist to specify the type of stock morphology desired at the time of outplanting so that nursery staff can adjust cultural practices to produce the desired results. For example, to minimize transpiration stress during the critical first year of seedling establishment after outplanting, reforestation foresters in interior California typically order seedlings with relatively shorter shoots and larger root systems.

Stock Types

Three basic types of conifer nursery stock are available for reforestation projects in California: container, bareroot, and plug +1. Choice of stock type is influenced primarily by the biological limitations of the site to be planted and the economic resources and preferences of the reforestation forester. In the Sierra Cascade region, the primary limiting factor is soil moisture during the growing season but other factors, such as low humidity, extreme temperature regimes, and herbivory, influence stock type choice as well. Storage capacity may influence choice of stock type because large container stock or plug+1 transplants are packed at lower numbers of seedlings per container than small container stock or 1+0 bareroot seedlings.

Container Stock

Container (or containerized) seedlings are the predominant stock type used for reforestation in California. Container seedlings are grown in potting media in small, usually multiple-celled containers with at least part of the production cycle carried out in greenhouses. Container seedlings are often referred to as plug seedlings because the root system and the media it was grown in remains intact (i.e., retains the shape and size of the cell in which it was grown, throughout the packing, storage, transportation, and planting process. When soil conditions are favorable, the intact root system of a properly grown plug seedling will grow rapidly and become established on the site quickly, often within two to four weeks of planting. This potential for rapid establishment, and the resulting rapid shoot growth, is the key benefit of using plug seedlings in reforestation.

Figure 6.1 Container Seedling Size.

Use of plug seedlings for large scale reforestation projects in western North America began in the 1970s with the development of a variety of multi-celled containers made out of an assortment of plastic materials (Cleary et al. 1978; Tinus and McDonald 1979). It was not until the late 1980s and early 1990s that the nursery technology improved such that reforestation foresters in the hot, dry summer climate of interior California started using significant amounts of plug seedlings in their reforestation programs. As the technology matured during those decades, growers focused on using a few standard container formats (Landis et al. 1990; Rose and Haase 2006).

Container Size

In the western US and Canada, molded styrofoam blocks and other container types are available in a wide range of cell volumes, depths, and densities. The comparative minimum size of deliverable seedlings varies by container size and by species. (See Appendix A for examples). Experience has shown that if seedlings grow rapidly after planting, initial seedling size becomes inconsequential within a few years. The container size chosen by the forester is based on the desired specifications, cost, storage limitations, and site conditions such as water availability and animal browse.

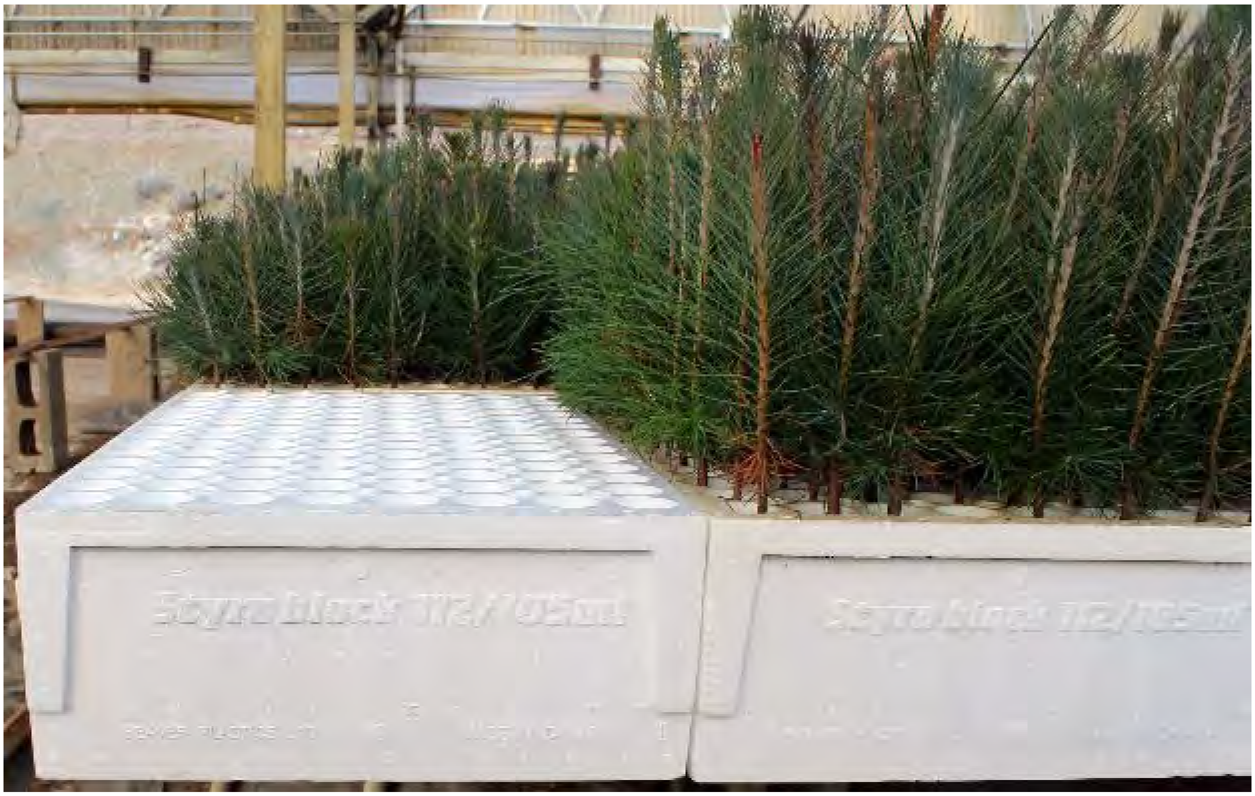

Figure 6.2 Styroblock are manufactured with many different sizes of cells and density. This is a Styroblock 112/105. This means there are 112 cells in a standard size block (14" x 24"). volume of the cell is 105 ml (about 6 cubic inches). The seedlings are 1 year old ponderosa pine.

The preferred container for each species may vary from nursery to nursery. Species that produce a substantial number of lateral branches as first year seedlings will need more growing space than species that remain single stemmed. Douglas-fir and white fir are examples of species that grow lateral branches in containers. Sugar pine and Engelmann spruce are species that do not branch very much during the first year of growth.

Planting site location and conditions may also influence the container choice. For instance, if site access is difficult, smaller seedlings are easier to transport, particularly if large number of seedlings are required or if the soil is very rocky, smaller seedlings are easier to plant.

Seedlings from larger containers tend to be more browse resistant because they are taller and have a larger woody stem and more buds. However, if heavy browse pressure is likely on the site, mechanical browse protection may be necessary after planting [see *Chapter 7 – Planting*]. The extra height of seedlings grown in larger containers is also beneficial on sites where moisture is not limiting and seedlings have to outgrow competing vegetation.

Bareroot Stock

Bareroot seedlings are produced by sowing seeds directly into the soil in prepared nursery beds. After one or two growing seasons, during which the grower applies a series of cultural practices designed to enhance both the roots and shoots, the seedlings are dug (lifted) from the soil, graded, and packed for storage or shipment. Common types of bareroot stock are described as 1-0, 2-0, and 1-1. The first number represents the number of seasons the seedling grows in a nursery seedbed and the second number is the number of seasons the seedling is grown in a transplant bed. Seedlings are transplanted to enable culling of poorly developing stock and planting into lower densities.

Each bareroot stock type has distinct features that affect its suitability for planting on various sites. One-year-old bareroot stock (1-0) has a small shoot and a small root system. Two-year-old bareroot stock (2-0 and 1-1) has a higher root-to-shoot ratio, greater stem diameter and height, and a much more developed and fibrous root system than 1-0 stock.

When compared to container stock, bareroot stock is generally slower to grow roots after outplanting, may require more careful handling, is sometimes more difficult to plant, and offers less production flexibility. However, bareroot stock usually cost less and may ultimately perform as well as container stock depending on site conditions. Weather can affect bareroot seedling production resulting in limited lifting and packing windows during years when there is excessive precipitation in late fall and early winter, the optimum time for lifting and long-term storage.

Proper handling of bareroot stock is much more critical than handling of containerized stock because of the potential dessication and physical damage to the exposed root. If the fine root hairs are subjected to dry air during the handling and planting process, then survival can be diminished. Initiation of root growth in the packed seedlings during storage is also a potential problem because the new growth if very susceptible to damage in the storage facility. Freezing the bareroot stock is advisable if long-term storage before planting is planned. It is absolutely necessary to place bareroot seedling roots vertically in the ground without any sweep or “J” roots in the soil. [*Ch. 8 – Planting*.]

The overall growth potential for bareroot seedlings is very good and this stock type can yield excellent results if rigorous standards for storage, handling and planting are adhered to as described in the Planting chapter of this manual. Better bareroot planting success has been achieved with PP compared to true firs and DF. Bareroot seedlings may also be less expensive, especially if larger seedlings are needed, although planting costs may be more.

Plug-1 Stock

Plug-1 (P-1) stock is produced by growing the seedlings in a small container for one growing season and then transplanting it into a bareroot nursery bed for the second growing season. Plug-1 seedlings typically have large tops and stem diameters as well as large, fibrous root systems. The limited benefits of planting large seedlings on sites with low soil moisture availability means that P-1 seedlings are not often planted in California. In some cases, however, where there is excessive animal browse or competing vegetation cannot be controlled, a P-1 seedling may be a good choice. Competition for light, not soil moisture, should be the limiting factor on the site. This consideration usually limits the use of the P-1 to humid coastal areas of northern California.

Choosing a Nursery

Highly successful reforestation programs require a solid, positive relationship between the nursery and the forester. This relationship includes not only seedling production but all of the timing, handling, storage and shipping factors that also contribute to the success of a program (Haase 2014).

Evaluating and working with nurseries

The most important consideration when choosing a nursery is the ability of the facility to produce the target seedling for the planned sites. As discussed earlier in this chapter, successful seedlings must be able to rapidly grow roots into the surrounding soil after planting. This means that when the seedlings leave the nursery the root systems must be physiologically ready to grow, they must contain sufficient nutrients to support rapid growth, and shoots must be able to survive conditions present on the site at the time of planting (light, heat, wind, humidity). In practice, it can be difficult to evaluate seedlings for these characteristics prior to out planting. The most reliable indicator of a nursery's ability to produce successful planting stock is past performance of its out-planted trees over a period of years.

Other considerations when choosing a nursery are easier to evaluate. These may include:

- the ability of the nursery to provide a sowing, packing, and shipping schedule that works for your reforestation program,
- storage capability by the nursery,
- efficiency of seed use (quantity of seed required to produce a given quantity of seedlings),
- capacity to produce sufficient quantities,

- ability to meet contracted volumes with target specifications,
- consistency in quality from year to year,
- flexibility to respond to changing conditions,
- ability to ship seedlings in the desired planting window,
- price.

A further consideration is weighing the convenience of having all seedlings growing at a single facility against the potential reduction of risk that may result from having seedlings at more than one location. Price per seedling should be a secondary consideration compared to the eventual return on investment that is dependent on obtaining quality seedlings that will perform well when planted, thereby avoiding the need to replant and/or the possibility of delayed stand development.

Nursery Cultural Practices

Nursery growers take advantage of location, facilities, and practices to manipulate the characteristics of seedlings and, in rare cases, clonally produced planting stock. There can be substantial variations in facilities and practices as nurseries "tune" their production program to the conditions at a particular location.

Location

Container nurseries usually use greenhouses to modify ambient conditions for all or part of the year, but extremes of heat and cold, as well as ambient light and humidity can still affect seedlings. Location can strongly affect the conditioning (hardening) of seedlings to prepare them for outplanting. Most seedlings in California need foliage that can withstand full sun and low humidity at the time of planting, therefore nursery locations that have similar conditions during the growing season may give the growers more options for conditioning.

Location is particularly important for bareroot nurseries, where field production is subject to ambient conditions at all times of the year. Bareroot nurseries must also be located in areas where there is good quality agricultural soil.

Facilities

Growing facilities must be able to provide appropriate environmental conditions for each of the three main phases of crop development:

1. Optimal moisture, temperature, and humidity during the **germination and early growth phase**.
2. Sufficient exposure to ambient temperatures, humidity, and light consistent with species requirements for good growth during the **rapid growth phase.**
3. Protection from extreme cold during the **hardening phase**.

Figure 6.3 A double-layer polyethylene gutter-connected greenhouse designed to grow tree seedling sin California. Note the roll-up walls and the black-cloth system for dormancy induction using shortened photo-period. There are also lights to extend the photo period.

Nurseries use irrigation, fertilization, heating, integrated pest management, ventilation and, for certain species, photoperiod extension lighting to optimize growing conditions for each phase of crop development (Landis et al. 1990, 1992, 1994). To provide maximum exposure to ambient conditions, conifer seedling production greenhouses typically have full roll-up walls, removable or retractable roofs, and/or transportable benches that allow movement of the crop in and out of the greenhouses as needed. The ability to expose the crop to ambient conditions can also help with timely dormancy induction. Some greenhouses may also include blackout equipment that permits the grower to induce dormancy by artificially exposing seedlings to shortened day lengths. In certain locations, greenhouses serve to protect the crop from possibly lethal low temperatures when the crop is dormant, as well as during the vulnerable germination and early growth phase.

Growing practices

Even though a quality seedling is likely to have the same basic set of characteristics regardless of nursery, the practices employed to grow that seedling can vary widely because of differences in location and facilities. Therefore, a successful growing program needs to anticipate crop needs based on past experience at the location, monitor crop parameters at appropriate intervals, and then respond to any deviations from the desired condition.

Figure 6.4 Irrigation pumps and fertilizer injector.

Table 6.1 describes the important elements for an annual crop schedule. Each activity may occur over a wide range of calendar dates depending on the location, the species being grown, the target characteristics, and the shipping window. Table 6.2 shows parameters of a growing crop that should be monitored within the nursery.

Table 6.1 Schedule of Nursery Activities for Seedlings

Activity	Time	Comments
Seed receipt and stratification	Nov-May	Pre-sow seed treatments (usually cold-moist stratification) may require 0 to 120 days depending on species.
Sowing and germination	January to June	Sow dates vary depending on species, stock type, and customer planting dates. Relatively high temperatures encourage rapid and uniform germination.
Rapid growth	March-August	Depends on growth rate of the species, the stock size, and timing of hardening off. High rates of irrigation and fertilization and photoperiod enhancement for some species.
Hardening-off, dormancy induction	July-September	Depends on species, customer ship dates, and sow date. Practices may include nutrient and moisture stress, exposure to ambient conditions and/or artificial reduction of photoperiod
Packing for immediate planting	September-February	Seedlings may be packed as early as late August if they are to be planted immediately. Seedlings may be shipped for planting through the winter to mild climate areas along the coast and in southern California.
Packing for storage	November-February	Packing for storage begins after seedlings are fully dormant, and must be complete before they break dormancy in the early spring.
Shipping	September to June	Seedlings are shipped to customers for immediate planting from September through February, for storage from November through February, from refrigerated storage from December through April, and from freezer storage from March through June.

Table 6.2 Crop Monitoring at the Nursery

Parameter	Interval	Purpose
Block weight	1-3 days	Determining when to irrigate. Other methods of determining irrigation timing are also used.
Media electrical conductivity	Each irrigation	Prevent build-up of excess salts
Media pH	Each irrigation	Maintain media pH at appropriate level
Shoot tissue analysis	2-6 times per year	Verify nutrient content of seedlings, particularly as they approach the end of the growing season. Especially useful when developing a nutrient regime for a crop.
Shoot height and caliper	1-4 weeks	Keeping crop on track to meet minimum and maximum specifications
Insect traps	As needed	Different locations have different pests.
Disease monitoring	On going	Greenhouse staff should monitor for disease as is seasonally appropriate.

Nursery Seed Need Considerations

The availability of quality seed appropriate for a given site is often the most critical limiting factor for reforestation projects. Seed shortages can be particularly problematic for non-industrial forest landowners who usually have not collected seed from their property. The efficiency of seed use (i.e., seedling yield for a given amount of seed) by nurseries is strongly influenced by the quality of the seed that is available. As is discussed in the seed chapter of this manual, seed quality is usually assessed as germination percent under a pre-treatment and germination regime specified for the species. Germination potential is influenced by species, collection year, cone handling and seed processing. But even with the same seed lots, seed use efficiency can vary considerably among nurseries, depending on such factors as seed treatment practices, sowing strategy, capability of sowing equipment, and sensitivity of the nursery managers to need for efficient seed use.

Pre-sowing seed treatment practices, including seed sanitation, soaking methods, length of stratification (i.e., cold moist) treatments, and conditions during the stratification treatment, can influence seed use efficiency. Many benefits result from these types of practices (Table 6.3).

Figure 6.5 Stratification cooler for conifer seed. The seedlots clearly identified in individual trays. Seed requires oxygen when in stratification. Large lots are divided into multiple trays so that the seed is in thin layers and can 'breathe".

Table 6.3 Importance of Seed Treatment Practices

Seed treatment practice	Benefits to seed use efficiency
a) Pre or post soak sanitation treatments	b) Reduction of seed borne diseases
c) Rinse and aeration during soak	d) Reduction of seed borne diseases and maintenance of seed health
e) Monitoring seed moisture content during stratification	f) Maintaining seed health, reduction of molds
Length of stratification (Stratification means soaking dry seed to 30-35% moisture content then storing it at 34-36 degrees F for a period of time)	For many species longer stratification (up to 120 days) may result in faster more uniform germination at cooler temperatures.

Sowing strategy, including seeds per cell for containers or seeds per bed foot for bareroot, as well as oversow requirements, also influence seed efficiency. For example, a nursery may choose to sow multiple seeds per container cell. This strategy will improve the chances that each cell has a germinated seedling, but there will be more cells with 2 or more seedlings that will need to be thinned out and discarded. The result is more efficient use of growing space in the nursery but less efficient use of seed because many good seedlings are discarded. If the nursery chooses to sow fewer seeds per cell, it will have to increase the number of cells sown to make up for the increase in the number of empty cells. This alternative strategy will result in greater efficiency of seed because fewer seedlings will be discarded. Nursery sowing strategies may, in part, be dictated by the sowing equipment used by the nursery. If the reforestation forester knows that seed is in short supply, informing nursery operators of the situation can lead to better efficiency, although perhaps with some adjustment in price.

Figure 6.6 High-speed vacuum seeder sowing styroblocks in a forest nursery. Above the seeder is a display with information about the seedlot that is used to guide the sowing process.

Packing

When seedlings are ready, the nursery will extract them from the containers or lift them from the soil (bareroot) and prepare them to be shipped for planting or cold or freezer storage. Seedlings are packed in boxes or bags for transportation and/or storage.

Packing Container Seedlings: The nursery will remove the seedlings from the containers with the root 'plug' intact. For most species, the plug will be nearly the same depth as the original container. For some species, particularly the true firs (*Abies*), the plug may form only in the bottom portion of the container because no lateral roots grow in the upper part. Field experience has demonstrated that these seedlings will still perform well after outplanting if they meet other seedling specifications.

Seedling extraction may be by machine or by hand, depending on rooting density of the species and the equipment available at the nursery. After extraction, seedlings are culled to remove those that don't meet specifications and the shippable seedlings are counted. A

Figure 6.7 A containerized seedling extraction, grading and packing line.

pre-determined quantity of seedlings is placed in a plastic bag, or bundled together by tightly wrapping the plugs with plastic wrap. The bagging or bundling protects the root systems from drying and provides some physical protection for the seedlings during handling and storage.

The bags or bundles are then placed in a packing box or crate with the seedlings either upright, or on their sides. Boxes of seedlings going into storage will be lined with a plastic bag that fully encloses the bagged seedling to reduce moisture loss. Lining is usually not needed for seedlings that will be directly planted. A lining can be detrimental to seedlings packed for fall planting because the lining will reduce ventilation and increase heat buildup in the box or bag.

The corrugated packing boxes used by nurseries vary considerably in size and type of cardboard. Foresters should consider the following:

- The type of cardboard used is important:
    - Boxes made with un-waxed cardboard will not withstand much moisture. Good liner bags and complete protection from external moisture during storage and transportation are essential. This type of box cannot be stacked very high without racking.
    - Boxes made with fully waxed (cascaded) cardboard will maintain their strength even when subjected to rain and moisture. These boxes are also much stronger than un-waxed boxes, particularly if they are made with high strength cardboard. Such boxes can be reliably stacked quite high without failure if they are properly secured to a pallet.
- Box size also affects seedling handling and storage:
    - The size of the box affects the number of seedlings in the box, and most importantly, the weight of the box. Boxes over 50 lbs can be more difficult to handle and transport in the field.
    - Boxes should be large enough to allow the tallest seedlings to fit with little or no bending of the shoots.
    - The required size and shape of the boxes is dictated in part by how the seedlings are

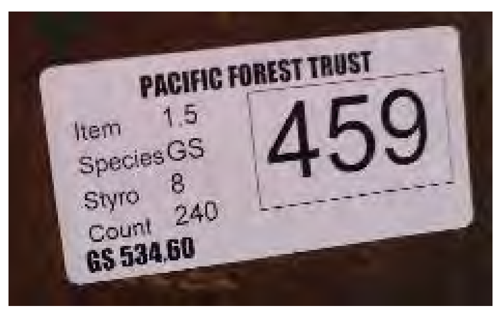

Figure 6.8 This box label has important information about the seedlings: species (Giant Sequoia), container size (styro 8), number of seedlings in this box (240), the seed source (GS 534.60, collected in Cal. seed zone 534 at 6000 feet), the nursery lot #(459), and the organization that contracted for the seedlings (Pacific Forest Trust).

arranged in the box. Seedlings placed upright in the box will generally take more space than seedlings lying flat in the box.

Nurseries should place labels on both the outside and inside of the box. Outside labels can be lost during transportation and storage, particularly from waxed cartons. The label should at minimum show the customer name, seedlot identification familiar to the receiving forester, and the quantity of seedlings in the box.

Figure 6.9 Pallets of packed seedlings awaiting transport to cold storage. The spacers between the boxes indicate that these will be stored frozen at 28 degrees. The spacers help the seedlings freeze faster and allow uniform thawing without removal from the pallets.

Boxed seedlings are often placed on wood pallets (that is, "palletized") at the nurseries. This procedure can greatly reduce handling for users who have a forklift available. If pallets are used, they need to be of adequate size to fully support the seedling boxes. Boxes may also be handled individually and stacked for transport and storage. The *Planting Chapter (8*) contains more details about shipping, handling, and storage.

Packing Bareroot Seedlings: From the time they are lifted until they are bagged, bareroot seedling roots must not be allowed to dry. After lifting, seedlings that don't meet specifications are culled and the shippable seedlings are counted into bundles.

The bundles may be packed in durable plastic lined paper seedling bags that are manufactured especially for this application. The bags are manufactured in a variety of sizes and can be large enough to contain very large bareroot transplants. Seedlings may also be packed in waxed boxes with plastic liners that sometimes contain moist packing material such as sawdust. The bags or boxes are sealed to prevent moisture loss and labeled as specified in the container section. Seedlings stored in the bags typically will need support racking for storage or long distance transportation. Boxes may be stacked or placed on racks depending on their weight and rigidity.

Ordering Seedlings

The seedling order for a reforestation project is best undertaken after a detailed plan and schedule of activities has been developed, as presented in *Ch.3-Planning*. Because no planting project can happen without appropriate seed, one of the first steps is to be sure that seed is available for the project. Planning activities such as the site assessment, the defining of specific objectives and the development of a prescription and a schedule of activities will determine all of the information necessary to place a seedling order with a forest nursery. Note that the schedule of activities advocated in this manual anticipates the need for seedlings with sufficient lead time that they can be custom-grown in a forest nursery for each project.

A riskier approach is to attempt to buy appropriate seedlings just before they are to be planted from nurseries that have grown them on a speculative basis for walk-in sales. Because of the large number of seed zones and species in the California, and the large variation in climates and altitudes, finding seedlings of the desired stocktype and species grown from appropriate seed is nearly impossible. Seed is often in short supply so no one wants to waste it on seedlings that don't sell. Sometimes seedlings that are useable can be found in nurseries, or excess seedlings can be obtained from nearby large landowners or public agencies, but it is strongly recommended that seedlings be ordered in advance to be grown for each specific site. Advanced ordering, usually called contract production, is the process that is discussed here.

A nursery seedling orders is for a quantity of seedlings, typically expressed in 1000's, of a particular stocktype and species to be grown from appropriate seed and delivered during a particular timeframe. Additional considerations include: when the order should be placed; the availability of an adequate amount of seed to produce the desired quantity of seedlings; and how the payment will be structured.

The needed quantity of seedlings is determined by the acreage of the area to be planted and the density (trees per acre). The choice of stocktype will determine whether the order will be placed with a container nursery or a bareroot nursery. Each of these nursery types will need to know which stocktype is specified for the project. For container nurseries, this stocktype is a container size; for bare-root nurseries, the stocktype is years in production and whether it is a transplant. The nursery may have a preferred stocktype for the desired species. Detailed discussions of stocktype and species can be found earlier in this chapter and in *Ch. 8-Planting-Species, Stocktype, and Spacing.*

Nurseries should be contacted well in advance to determine when orders need to be placed. Each nursery has a different order window, and this timing may vary depending on the species to be ordered. At the time of order, the nursery will need information about the seed to be used including species, seed zone and elevation, seeds per pound, purity, and germination percentage. This information will be used to calculate how much seed is needed. Large forest landowners and public agencies typically already have the seed they want to grow. Landowners without seed should have already determined a source of appropriate seed during the planning process. Sometimes this source can be the nursery. [*Ch.3-Planning-Obtain Appropriate Seed*]

When the order is placed, the nursery should be made aware of the anticipated delivery timeframe and whether the seedlings will be planted immediately after they are packed for delivery, or will be placed into storage. [*Ch. 8-Planting-Receiving Seedlings from Nursery*]

The contract between the seedling purchaser and the nursery will typically include all of the conditions detailed above plus seedling size specifications, usually minimum height and stem caliper, and payment terms. Payment terms will vary between nurseries. Nurseries typically require an advance payment at the time on the order of 25 to 40%. This payment is based on the quantity ordered. There may be additional progress payments as the crop matures. The final payment will be due at the time of delivery and will be based on the quantity actually delivered. Most lots will have a small variation in quantity, either over or under the order quantity. Purchasers are usually not required to buy excess seedlings if any are produced, but most do.

Seedling Storage, Shipping & Handling

Careful handling and storage of seedlings after lifting is crucial for ensuring the best possible outcome for seedling survival and growth. Care should be taken to avoid common stressors such as elevated storage temperatures, rough handling, and desiccation (Landis et al. 2010).

Cold Storage

Cold storage of packed seedlings is a common practice in California and throughout western North America (Camm et al. 1994). Cold storage of seedlings requires constant temperatures of 33-36°F inside the seedling boxes or bags to maintain optimum seedling quality. The temperature inside the storage boxes is usually somewhat higher than the air temperature in the cooler facility due to seedling respiration and the insulating qualities of the media and the storage boxes. Therefore, good air circulation around the storage boxes is essential. Temperature monitoring should include both the air temperature in the cooler and the internal temperature of the storage boxes.

Figure 6.10 Boxed container seedlings in cold storage.

Temperatures above 36°F in cooler storage will result in reduced seedling vigor due to loss of stored carbohydrates to increased respiration. Additionally, seedlings may break dormancy and initiate root and/or shoot growth in the box or bag if cooler temperatures are too high. Warmer storage box temperatures also favor the development of post-harvest gray mold (*Botrytis*) that will lead to a rapid deterioration of seedling quality. During transport to the planting site, seedlings must continue to be protected as much as possible from the same potential stressors of heat, rough handling, and desiccation. Refrigerated boxes on pickups or trailers are excellent ways to transport seedlings to the field, but not absolutely necessary. Judicious use of tree tarps and placing the trees in the shade will help prevent heat buildup in the storage containers.

Freezer Storage

Freezing seedlings for long-term storage is a good method to ensure that the seedlings remain in stasis and to prevent development of *Botrytis* when longer storage durations are needed (e.g., for high-elevation sites that are snowed in until late spring). Freezer storage is best done at temperatures of 25-30°F and in boxes that have polyethylene liners to prevent seedling desiccation. Seedlings can be stored for 6-8 months in freezer storage.

Good air circulation through the pallets of trees is important so all seedlings freeze in a short time period. This can be accomplished with the use of spacers between boxes on pallets and maintaining space between pallets for air circulation. These spacers between will also facilitate uniform thawing when seedlings are removed from storage.

The speed at which frozen plants are thawed is an operational variable that has been studied across tree nurseries across Western North America. In British Columbia, Camm and others (1995) studied the physiological effects of thawing regimes on container spruce seedlings and found no significant differences between rapid thaw (1-2 days at 60°F) and slow thawing (17 days at 41°F). The Nursery Technology Cooperative at Oregon State University in a similar study found no significant difference between slow and rapid thawing periods or for stock that was rapid thawed and then held in cold storage (Rose and Haase 1997).

There can be accelerated development of *Botrytis* with both thawing methods compared to seedlings that are never frozen. Outplanting seedlings as rapidly after thawing as possible is strongly recommended. In the case of rapid thaw, weather conditions can be considered and thaw timing can correspond with a period of favorable planting weather. If slow thawing is underway and the weather turns unfavorable for planting, it is inadvisable to re-freeze the seedlings if they have been thawing for more than one week. Rapid thawing also requires a moderate, relatively controlled temperature that may not be available at high altitude when daytime temperatures remain below 60°F and dip below freezing at night.

When thawed trees are delivered to the field, it is important that the thawing is uniform throughout the containers. Partially frozen seedlings, or bundles of seedlings, should not be torn apart in the field as root damage is likely to occur.

Shipping & Handling

Bareroot seedlings are especially intolerant of poor storage conditions, rough handling, and desiccation during delivery to the field. The effects of handling stress in outplanted seedlings may not be evident until weeks after planting. Damage to the roots can occur during shipping, handling, and planting. It is important to make certain that handlers and planters do not drop the boxes or throw bags of seedlings, and that the seedlings are never subjected to dry or windy conditions. It is unfortunately common on planting sites to observe tree boxes being thrown out of the back of a truck or seedling boxes exposed to direct sunlight. Both of these practices negatively influence seedlings and must be avoided.

Bareroot seedlings are damaged very easily when the roots are exposed to dry conditions and caution must be used when removing the seedlings from the packing bags or boxes and placing them into the planter's bags. Dipping seedling roots in water can also help to minimize damage by desiccation. Exposure to dry conditions for just a few minutes can cause significant reduction in survival. [*Ch. 7 – Planting*.]

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References

Camm, E.L., Goetze, D.C., Silim, S.N., and D.P. Lavender. 1994. Cold storage of conifer seedlings: an update from the British Columbia perspective. *For. Chron.* 70:311–316.

Camm, E.L., Guy, R.D., Kubien, D.S., Goetze, D.C., Silim, S.N., and P.J. Burton. 1995. Physiological recovery of freezer-stored white and Engelmann spruce seedlings planted following different thawing regimes. *New Forests*10(1):55–77.

Cleary, B.D., Greaves, R.D., and R.K. Hermann. 1978. Regenerating Oregon's Forests: A Guide for the Regeneration Forester. Oregon State University Extension Service. Corvallis. 286 p.

Davis, A.S., and D.F. Jacobs. 2005. Quantifying root system quality of nursery seedlings and relationship to outplanting performance. *New Forests* 30:295-311.

Dumroese, R.K. , Landis, T.D., Pinto, J.R., Haase, D.L., Wilkinson, K.W., and A.S. Davis. 2016. Meeting forest restoration challenges:Using the target plant concept. *Reforesta* 1:37-52.

Haase, D.L. 2008. Understanding forest seedling quality: measurement and interpretation. *Tree Planters' Notes* 52(2): 24-30.

Haase, D.L. 2011a. Seedling phenology and cold hardiness: moving targets. In: Riley, L.E., Haase, D.L., and J.R. Pinto (tech. coords.), National Proceedings: Forest and Conservation Nursery Associations – 2010. Proc. RMRS-P-65, USDA Forest Service, Rocky Mtn. Research Station. Fort Collins, CO. pp. 121-127.

Haase, D.L. 2011b. Seedling root targets. In: Riley, L.E., Haase, D.L., and J.R. Pinto (tech. coords.), National Proceedings: Forest and Conservation Nursery Associations – 2010. Proc. RMRS-P-65, USDA Forest Service, Rocky Mtn. Research Station. Fort Collins, CO. pp. 80-82.

Haase, D.L. 2014. A quality relationship between nurseries and foresters is imperative to successful reforestation. Society of American Foresters. *Western Forester* 59(1): 1-7.

Hessburg, P.F., Goheen, D.J., and R.V. Bega. 1995. Black stain root disease of conifers. USDA Forest Insect and Disease Leaflet 145. 11 p.

Hessburg, P.F., Agee, J.K., and J.F. Franklin. 2005. Dry mixed conifer forests of the Inland Northwest, U.S.A: contrasting the landscape ecology of the presettlement and modern eras. *Forest Ecology and Management. 211(1): 117-139.*

Landis, T.D., Dumroese, R.K., and D.L. Haase. 2010. Seedling Processing, Storage, and Outplanting. Vol. 7, The Container Tree Nursery Manual. Agric. Handbook 674. USDA Forest Service, Washington, DC. 200 p.

Landis, T.D., Tinus, R.W., McDonald, S.E., and J.P. Barnett. 1990. Containers and Growing Media, Vol. 2, The Container Tree Nursery Manual. Agric. Handbook 674. USDA Forest Service. Washington, DC. 88 p.

Landis, T.D., Tinus, R.W., McDonald, S.E., and J.P. Barnett. 1992. Atmospheric environment, Vol. 3, The Container Tree Nursery Manual. Agric. Handbook 674. USDA Forest Service. Washington, DC. 145 p.

Landis, T.D., Tinus, R.W., McDonald, S.E., and J.P. Barnett. 1994. Seedling Nutrition and Irrigation, Vol. 4, The Container Tree Nursery Manual. Agric. Handbook 674. USDA Forest Service. Washington, DC. 119 p.

Linden, Leena. 2002. Measuring Cold Hardiness in Woody Plants. PhD Dissertation. University of Helsinki.

Mexal, J.G. and T.D. Landis. 1990. Target Seedling Concepts: Height and Diameter. In: Rose, R.; Campbell, S.J.; Landis, T. D., eds. Proceedings, Western Forest Nursery Association; 1990 August 13-17; Roseburg, OR. General Technical Report RM-200. Fort Collins, CO: USDA, Forest Service, Rocky Mountain Forest and Range Experiment Station. pp. 17-35.

Ritchie, G.A. 2006. Chlorophyll fluorescence: What is it and what do the numbers mean? In: Riley, L.E., Dumroese, R.K., Landis, T.D.: tech. cords. 2006. National Proceedings: Forest Conservation and Nursery Associations-2005. Proc. RMSR-P-43. Fort Collins, CO: U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Research Station. 160 p.

Rose, R. and D.L. Haase. 1997. Thawing regimes for freezer-stored container stock. *Tree Planters' Notes* 48:12-17.

Rose, R. and D. L. Haase. 2006. *Guide to Reforestation in Oregon*. College of Forestry, Oregon State University. Corvallis. 48 p.

Simpson, D.G. and G.A. Ritchie. 1997. Does RGP predict field performance? A debate. *New Forests.* 13: 253-277

Tinus, R.W. and S.E. McDonald. 1979. *How to Grow Tree Seedlings in Containers in Greenhouses*. Gen. Tech. Rept. RM-60. Rocky Mtn. Expt. Station, USDA Forest Service. Ft. Collins, CO.

Appendix A: Comparative Seedling Target Sizes by Container Size and Species

Species	Container Size	Minimum Height (cm)	Minimum Caliper (mm)
Douglas-fir	2	6	1.5
	5	12	2.3
	6	12	2.5
	8	12	3.0
	10D	12	2.7
	10	12	3.0
	15	12	3.2
	20	12	3.5
Incense Cedar	8	10	2.8
	10D	12	3.7
Jeffrey Pine	5	8	2.5
	6	8	2.7
	8	8	3.0
	10D	8	2.7
	10	8	3.0
Lodgepole Pine	5	8	2.3
	6	8	2.5
	8	8	2.7
	10D	10	2.7
	10	10	3.0
Ponderosa Pine	2	8	1.7
	5	10	2.5
	6	10	2.7
	8	10	2.8
	10D	10	2.8
	10	10	3.0
	15	10	3.5
Red Fir	2	6	1.5
	5	8	2.0
	6	8	2.3
	8	8	2.5
	10 & 10D	10	3.0
	15	12	3.2
	20	15	3.5
Sugar Pine	5	8	2.0
	6	8	2.2

Species	**Container Size**	**Minimum Height (cm)**	**Minimum Caliper (mm)**
	8	8	2.4
	10D	10	2.4
Western White Pine	5	6	2.0
	6	6	2.3
	8	8	2.5
White Fir	2	6	1.5
	5	8	2.0
	6	8	2.3
	8	8	2.5
	10D	10	2.7
	10	10	2.8
	15	12	3.0

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Chapter 7:
Site Preparation

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> "Site preparation is the single most important step in the reforestation process"
>
> Professor Michael Newton

Introduction

Site preparation refers to any measure taken to prepare the site for regeneration of a forest stand following harvest or wildfire or reforestation of a brush field or other site in need. To achieve optimal forest stand growth rates, the common objective is to provide the best environment possible for seedlings, with ample root contact to bare mineral soil, adequate sunlight, sufficient levels of organic material to conserve soil moisture, and the reduction in vegetative competition. Other objectives include: reducing fuels to reduce future risk of fire, leaving enough organic debris to control erosion, leaving enough structure in the form of large woody debris (LWD), snags, hardwoods and other elements to provide for wildlife habitat, leaving some residual trees to mitigate visual aesthetics where needed. Balancing the primary objectives of the landowner with the broader expectations, and sometimes contradictory, of other interested parties is a challenge.

Determining Need and Constraints

Determining the need for site preparation involves many factors, some of them considered limiting factors (Hobbs, et. al., 1992) constraining seedling survival and some in need of mitigation, for example hydrophobic soils. It is also important to not create limiting factors in the process of site preparation. These factors revolve around creating the ecological conditions necessary to enable the survival of planted trees and the desired level of natural regeneration. The primary methods include: mechanical, chemical, burning or manual, with best results usually from an integrated combination. Logging in many situations can also assist in site preparation, such as whole tree logging or biomass harvesting and sending sub-merchantable material to cogeneration power plants. Some of the factors to consider that influence the decision on what method to use are discussed below.

Slash Loads and Fuels Loading

Historically the objective of site preparation activities has been to clear logging debris by piling with a brush rake, and sometimes with broadcast burning, to make the site plantable. Ripping (sub-soiling) is done by some landowners to expose mineral soil for the purpose of planting and to reduce the depth of slash through crushing. Heavy loads of logging debris or slash can be difficult to plant through and will add to the fuel load in the case of a future fire. Deciding how much slash to remove from a site for optimum growth and minimal risk to fire can be difficult. Slash loads that prevent proper planting access need to be addressed. For many landowners in fire-prone interior California, leaving a minimal amount of slash is necessary to help facilitate plantation survival to maturity given the future risk of wildfires. Other landowners with less available investment or that attach less importance to optimal stand growth rates may use less intensive treatments. Thompson (2011) found that a plantations risk of loss to wildfire decreases as age and tree size increases, and stand basal area decreases. Removing excess fuels through site preparation activities is the most influential factor in reducing risk of future fire (Weatherspoon and Skinner 1995). Peterson (2007) indicates lower basal area and low levels of surface fuels increases chances of survival. This indicates a need to maintain low fuel levels and control vegetation to increase growth rate to improve resilience. Slash levels for fuel models are generally classified as light, medium and high levels. Light slash is total fuel load of less than 11.5 tons per acre and fuel bed depth of 1 foot. Medium slash is described as being a total fuel load of 34.5 tons/acre and a fuel depth of 2.3 feet. Heavy slash loads are fuel depths of greater 3 feet. The level of slash loading will affect the rate of spread and the potential flame length. Stands of mixed conifer or mixed conifer and hardwood that are clearcut or heavily thinned are all represented by these medium and heavy fuel models. Medium and heavy slash loads should be considered a high priority for site prep treatments that reduce depth of slash and aid in rapid decomposition of residues. In post wildfire situations where high intensity fire has removed a high percent of the small material retention of the remaining organic material should be a priority.

Vegetative Competition

Beyond the need to remove slash to make sites physically plantable, the next most important limiting factor to reforestation success is vegetative competition. In a Mediterranean climate, the potential lack of available water is the most critical factor affecting survival of planted seedlings. The competition for available soil water can come from native species or invasive weeds. After disturbance from logging, fire or other, conditions are ideal for pioneer species to establish or recover and then dominate a site. A common goal to successfully regenerate a site is to control vegetation on a site for the first two years (year of planting and following year) so that most of the water is only used by the planted conifer seedlings. Keeping the vegetative cover below 30% ground cover for 5 years is best for optimal growth. Pioneer species are very adaptable and site preparation will only reduce their extent and water use temporarily. The soil seed bank and re-sprouting ability of many brush and hardwood species assures their long-term presence. Good site preparation will generally reduce the amount and expense of follow up release treatments that will be needed to achieve the desire level of conifer tree growth.

Soil Type

Soils are the foundation of the forest and its long-term productivity. Forest soils warrant our respect and attention to conserving them. Soil texture can influence what type or types of site preparation to use. Soils can range from fine textured heavy clays to very coarse sandy soils. In general, soils in California forests are loams to sandy loams due to the geology being primarily volcanic, sedimentary and igneous. Fine textured soils (clays) can be susceptible to compaction if operated on under wet conditions. Coarse soils are more erosive than fine textured soils. Decomposed granite for example is very erosive. Picking a logging system that minimizes soil disturbance while leaving the site clean enough to plant is preferred to a mechanical or burning site preparation method that can remove much of the organic matter that has a positive role in controlling erosion. On erosive soils, using proper logging and good chemical vegetation management as an integrated approach will usually achieve the best environmental outcomes with respect to soil erosion and negative downstream impacts.

Recent findings from 20 years of results from the North American Long-Term Soil Productivity (LTSP) experimental sites in California (Zhang et al. 2017) provides some guidance on the importance of organic material on the site and the relation between compaction and subsequent growth of the conifer seedlings. The study examined the effect of timber harvest activities on the residual organic material and effect of compaction. Biomass treatments included: 1) Remove tree boles. Retain crowns, felled understory, and forest floor; 2) Boles and crowns removed. Felled understory and forest floor retained; 3) all above ground biomass removed, including forest floor, with bare soil exposed. The three soil treatments were: 1) no compaction; 2) compact to an intermediate soil bulk density; 3) compact to a severe bulk density. Compaction treatments were intentional and over as much of the area as possible, not merely what occurred during logging. Contrary to popular belief, the treatments to the organic material had little effect on the subsequent growth of the planted conifers. Despite indications on several sites that nitrogen availability was reduced in the forest floor removal treatment, it was not limiting growth at 20 years. Compaction was also shown to have an insignificant effect on seedling growth and in some cases (primarily on coarse textured soils) proved to have a positive effect on growth, due to increased water holding capacity. No sites had negative effects of compaction when varying seedling survival was factored in.

These results are similar to 10-year continent wide results (Ponder, et. al, 2012) stating that: “organic matter removal had no consistent study-wide impacts on 10 year planted tree or total above ground biomass”, “soil compaction per se generally increased planted tree biomass on these predominantly coarser-textured soils, particularly in the absence of forest floor removal”, “vegetation control increased 10 year planted tree biomass and in many cases, foliar N concentrations, with positive responses usually occurring consistently across organic matter removal and compaction treatments". These results are contrary to international meta-analysis (Achat, et.al. 2015) of published data worldwide. Soil fertility losses from organic removal were shown to have negative consequences for the subsequent forest ecosystem, with tree growth reduced by 3-7% in the short to medium term (up to 33 years after harvest) in the most intensive harvests (e.g. when branches are exported with foliage). Ponder et al (2012) suggested possible contributing factors to the lack of negative response from organic removal and compaction in LTSP studies were: 1) most LTSP installations were on deep, relatively productive soils where nutrient limitations are less likely because of greater quantities and proportions left on site; 2) the operational nature of the full tree removal treatments on the less productive jack pine and black spruce sites whereby substantial quantities of fine and coarse woody material were left on-site; and 3) the potentially confounding but variable role that soil microorganisms may play in enhancing tree nutrition by utilizing otherwise inaccessible and/or mineral nutrient reserves.

LTSP installations in California and soils in general on most managed timberlands in California have the noted characteristics of mostly loamy and sandy loam to sandy soils that are tolerant of some compaction and with sandy soils there is some benefit to compaction. Many of these same soils are deep providing for a large reservoir of nutrients. We are blessed to have very manageable soils in California. But evidence from older multi-rotation studies (Achat, et.al. 2015) would indicate that we should still be diligent and wise to practice accepted best management practices (BMP's). Some include:

- not operating when soils are wet, especially on clay soils,
- Leave as much foliage as possible on site, especially on sensitive soils, like shallow, highly acidic, highly weathered and coarse textured soils.
- Do not remove the A horizon during operations

It is important to have the results of these studies in mind when trying to determine the method of site preparation appropriate for the site or if site preparation is necessary at all. The fundamental decision of implementing a site prep activity should be creating a positive environment for planting seedlings. Initial success depends on being able to plant the site well and long term optimum growth is dependent on proper planting. Long term growth increases from site prep activities that remove slash or mitigate compacted soils are less predictable, but we should still be cautious and avoid compaction at the time of harvest and retain organic material for optimum soil health.

Topography

Slope can also effect what options are available for site preparation. Steep ground has fewer options than gentle slopes. Options on steep ground are generally more expensive. Site preparation on steep slopes is usually limited to whole tree logging or broadcast burning. The whole tree logging usually leaves a significant slash load along roads, which needs to be burned. Broadcast burning is increasingly being limited by smoke management issues along with liability and cost associated with risk of escaped burns. Manual methods can be used but are very expensive. For mechanical methods, tractors are generally limited to slopes less than 35%. Excavator mounted equipment with self-leveling cabs can work up to about 45% slopes depending on soils. The Spyder can be used on slopes to around 65%. Trends of increased slash loads being left on steep slopes is becoming a fuel loading concern with deteriorating markets for small material and liability concerns.

Hydrophobic soils

Hydrophobic soils are usually the result of high intensity wildfire, often on coarse textured soils, and can generate considerable soil erosion after a wildfire (Certini, 2005; DeBano, 2000). Additional soil disturbance on coarse textured soils is usually not encouraged due to erosion risks. A 4-year study of erosion in sites with different combinations of post-fire logging and contour subsoiling treatments suggests that on moderately sloped sites affected by high-severity forest fires, salvage logging—particularly when implemented immediately post-fire—can substantially reduce erosion (James & Krumland, 2018). As noted elsewhere it is crucial that tractors follow the contour when subsoiling to avoid concentration of water in new ditches that can become gullies.

Compaction

Sub-soiling is the primary form of mitigation for compaction done by mechanical activities such as logging or piling. This is particularly applicable with clay soils. Sub-soiling to mitigate any present or past compaction also adds another mechanical disturbance to vegetation and makes for easier and less expensive planting.

Animals

Vertebrate pests can do significant damage to planted seedlings. These primarily are pocket gophers, deer and elk. Mountain beavers, rabbits, wood rats and voles can also cause damage. Manipulation of habitat is usually the long-term solution. Short term protection and control methods may be necessary. It is important to make sure that during the site preparation process habitat is not created that may encourage some pests.

Disease

When diseases are present or in the near vicinity the best time to deal with these are during harvesting and site preparation. Root rots that exist in stumps can transfer to young seedlings of susceptible species. Chapter 10 provides good guidance on how to deal with root rots and other diseases. Mistletoe is another example that is best dealt with during harvest and site preparation. Getting rid of the source within spreading distance of seedlings to be planted is the easiest solution.

Temperature

High temperature can be a problem especially with Douglas-fir (DF) seedling survival. Southerly facing slopes will always be hotter and should be a major concern. Burned surfaces or organic material generate hotter temperatures than bare mineral soil (Haig et al. 1941). Site preparation can improve conditions by creating bare mineral soil. With DF it is also important to leave LWD where possible to provide micro-sites for planting that provide some dead shade and shelter from afternoon sun. When planting in harsh sites, it is even more important to plant seedlings with small tops, good caliper and a high root to shoot ratio so that they will have a better chance of survival.

Low temperature can also be a problem too in the form of frost. Frost is particularly problematic with DF and the true firs. Higher elevations particularly on eastside flat locations are problematic. Air drainage is very important to providing conditions favorable to fir species. Site preparation activities that block air flow should be avoided. Clearing brush to improve air flow is helpful. DF should be planted on slopes where possible and avoid low lying flat areas particularly on the eastside. Areas that are known to be frost pockets should be planted Ponderosa pine or Lodgepole pine in extreme cases to ensure survival.

Costs

Economics have a significant influence on what types of site preparation are utilized and how much is spent. The time value of money encourages one to spend the least amount necessary up front due to the length of time the costs must be carried. By the same token good site preparation can significantly increase growth, helping to justify proper site preparation. Good site preparation also considerably reduces follow-up release costs. Lack of any site preparation or poor site preparation can also lead to a completely failed plantation and the need for a costly replanting.

Safety and Snags

Snags are increasingly are being left as wildlife habitat. Leaving snags must be done with operator and public safety kept in mind. The quantity, quality and location of snags retained needs to be well planned to minimize safety hazards. Snags should not be left within a tree length of roads due to public safety and to reduce spread of future fires. Roads are often used as fire lines and snags next to roads can cast sparks over fire lines the can speed the spread of wildfires. Snags should also not be left along ridge tops to help prevent spread of wildfire from embers that are carried in the wind. For operator safety, the removal of snags that are judged to be public safety or fire spreading risk should be done as soon as possible after the wildfire while snags are still sound and can be safely cut. As the snags age, they are increasingly prone to falling. Research conducted on Blacks Mountain Experimental Forest with a species composition of primarily ponderosa pine, white fir and incense cedar after the Cone Fire in 2002 calculated that 80% of snags fell within ten years (Ritchie, 2014).

Worker safety for the various forms of site preparation varies. The highest workman's compensation claims in reforestation activities are related to chainsaw work. Burning related activities are followed by equipment operation for frequency of injury. The safest activity related to site preparation was the application of herbicides (Newton and Dost, 1984). With current worker protection safety standards and the application of herbicides that do not affect mammals, the negative impacts of herbicide exposure to humans and mammals is minimal. There is always public concern about the potential of herbicide application to affect non target plants, fish, and animals. The use of hand application along with buffers on streams is a useful mitigation to limit public exposure where recreational users are more common.

Methods of Vegetation Control

There are many different methods for controlling unwanted vegetation, and the selection of the desired method is a keystone in the success of the reforestation project. These various methods that can be used in site preparation are introduced here and more detailed information for use beyond the site preparation phase can be found in other chapters within this book.

Mechanical

Mechanical site preparation includes logging, piling, sub-soiling, mulching, V-blading, terracing, mastication, chipping and other methods. There are many forms of mechanical site prep and many types of equipment that can be used to accomplish the basic objective of making a site plantable. The more complex objective of balancing fuel loading, erosion control, wildlife habitat, aesthetics and other goals including economics can be difficult. Ease of planting and ensuring a favorable environment for the seedlings should be the underlying goal of mechanical site prep.

Logging

Logging disturbance is a basic site preparation activity that can be one of the most cost effective of all the methods. Directing the logging contractor to remove the whole tree to the landing can provide both removal of excess organic material and some level of scarification. Construction of skid trails provides additional scarification. Site preparation achieved by logging may not be evenly distributed across the harvested area and may not achieve desired results.

A commonly used form of logging that can accomplish slash disposal and reduce the need for tractor piling is “whole tree logging”. Taking the whole tree to the landing takes most of the slash too. When markets are strong for biomass and cogeneration power this has been a popular method of logging for commercial and sub-merchantable materials. Leaving the material on site for a while (at least a month) after shearing allows drying time to facilitate chipping and maximizing haul weight to the cogeneration facility. It can also facilitate leaving more of the foliage and nutrients on site as more foliage will fall off during the skidding process when it is dry. It allows for the disposal of tops left on the landing and chipping of small material that is otherwise waste. Removing as much sub-merchantable material as possible can reduce the need or eliminate need for site preparation. Biomass thinning allows for understory thinning for fuels reduction that is a valuable treatment for reduction of fire risk.

There is one variation to whole tree logging that is being implemented due to the limited biomass markets and the diminishing infrastructure. The feller buncher (hotsaw) cuts all of the sub-merchantable material (3 – 10 inches in diameter) along with the merchantable timber (typically up to 23 inches in diameter at the stump) in a harvest unit. The skidding equipment is brought in along with a log processor and log loader at the landing. As the merchantable timber is processed at the landing the exiting skidding equipment grapple the unmerchantable tops and limbs from the processing operation at the landing and pack it back into the harvest unit, evenly spreading out the material. Repetitive turns from the unit to the landing and back additional dispersal and breakdown of the slash.

Figure 7.1 Unit with landing slash returned.

In-woods processing is another alternative that is being implemented and similar to the operations mentioned previously. In this operation, the log processor is placed in the unit to process logs previously bunched by the feller buncher. The processor removes the limbs and severs the tops of the merchantable trees from the boles leaving the material more evenly distributed throughout the unit. The skidding equipment grapples and skids a full payload of the processed logs to the landing. The logs can be decked or immediately loaded without any material generated at the landing. The action of the log processor moving through the unit along with the repetitive turns from the skidding equipment, allow additional dispersal and breakdown of the slash.

Figure 7.2 "In woods" processed logs.

Piling

Piling involves the gathering of the slash generated from logging activities with a brush rake mounted on a cat or excavator and placing it in piles or wind rows for burning. For the conversion of brush fields, the most common practice is to root out the brush and place it in windrows and after a period of drying, the windrow is rolled into a pile. This helps to remove soil that is being held in the roots. It is important to avoid including soil in the piles for two reasons. First, the top layer of soil or A horizon plays an important role in the initial establishment and growth of the seedlings because it is where the highest level of nutrients resides. When the A horizon is removed completely, the plantation may have poor growth for many years or fail to properly establish. Secondly, when there is soil incorporated into piles that are then burned, there is an increased possibility that incomplete burn consumption will occur in the piled material. This mix of soil and combustible biomass can lead to smoldering material that may reignite when conditions dry in the spring. Nutrient-rich soil in smoldering piles will also have organic matter and nutrient volatilization from heating intensity and duration, losing site nutrient capital. Piling can also be done by hand, but is cost prohibitive in most cases. Slope can be a limiting factor for mechanical site preparation as most equipment can't be used on slopes greater than 35 percent. In areas of high fire risk or subject to dry windy conditions, site preparation methods that don’t require burning may be a good alternative.

Figure 7.3 Cat with brush rake piling logging slash.

Sub-soiling

Sub-soiling or tilling is most commonly the practice of pulling a single or double set of shanks with winged sub-soilers through the soil with a tractor. Rock ripper shanks are also commonly used but do not fracture nearly as much ground as winged shanks. Wings on shanks should have only a slight angle from horizontal (less than 3 degrees). The objective is to lift and fracture not to plow. Sub-soiling to mitigate compaction primarily on clay and clay loam soils should target a minimum depth of 18 inches. Most compaction caused by mechanical equipment is present within the top 18 inches of soil. Because this method of site preparation causes a linear gully effect, it is extremely important that the feature is made on the contour. If not on the contour, it could lead to concentrated flow of surface water and increased erosion potential. This method of site preparation can be used in conjunction with other methods of mechanical site preparation or used as a single treatment. As discussed previously, this method has been used extensively in reforestation programs as mitigation for compacted soils. While this rationale for tilling may not be supported by scientific evidence for most of California soils, there are other benefits that can be achieved through the practice. Tilling after fire and salvage operations can have a beneficial effect on infiltration rate as it can break up hydrophobic layers that frequently develop in burned sites, particularly with coarse-textured soils. Tilling of coarse textured soils other than for mitigation of hydrophobic soils is not advised because it will reduce the water holding capacity of the soil. Tilling also serves to break up slash and incorporate it into the soil thus speeding up the breakdown of combustible material on the site, and perhaps benefitting soil organic matter (humus) development.

Figure 7.4 D8 with Winged Sub-soiler shanks.

Mastication

Mastication has been used extensively in the effort to reduce fuels at the wildland urban interface. It is an effective way to clear brush along fire breaks and reduce overall fire risk. More recently it has been used to reduce the fuel loads in harvested units and retain some of the benefits of providing a mulch layer to the soil. Mastication involves crushing or grinding vegetation on site with some type of specialized head mounted on a piece of heavy equipment. The type of equipment can range from small bobcat machines to large excavators. This method of vegetation control is expensive, but burning afterward is not necessary. Organic mulch that is left on site may also increase the water holding capacity of the soil (Hudson 1994). It is a good method to use when vegetation is very large hindering reforestation efforts. Masticating the vegetation (figure 3&4) will not kill most species and re-sprouting will most likely occur. It is best used in combination with herbicides for effective control. It is usually used more with release applications where large brush is present, but increasingly as a site preparation to avoid potential liability of burning. Due to risk of starting a fire by hitting a rock and creating sparks, many mastication operators prefer to avoid work during the hot dry summer months or work in areas that are less risky (rocky). Some units have foam units mounted on them to immediately put out a fire if one starts.

Figure 7.5 Before mastication.

Figure 7.6 After mastication.

Chipping

Chipping sub-merchantable, or unmerchantable, material prior to harvesting is a method to reduce the overall impact of having too much biomass on the harvest unit. The process is to cut all unmerchantable trees of all sizes for use as woody biomass. Typically, the biomass is cut and bunched with a feller buncher and then skidded to the landing where it is chipped into a van for shipping to a co-generation facility, this can be done as a pre-harvest like with a clearcut or as a post-harvest. Post-harvest chipping includes the cutting of the remaining unmerchantable material that is left standing after harvest and skid to the landing where it is chipped along with the top piles. Post-harvest logging debris can also be skid to the landing for chipping, further reducing the amount of organic material left in the harvested unit. Removal of biomass does not benefit the growth potential of the site as previously discussed, but it does facilitate the ease of planting and reduces the fuel load. Using biomass thinning can be a stand-alone site preparation treatment or it can be used in conjunction with other mechanical site preparation activities such as sub-soiling and/or with chemical treatment. Biomass chipping usually eliminates the need for piling and leaves more organic material on site to act as mulch that is particularly beneficial to Douglas-fir. Having more organic debris on site also reduces risk of erosion.

With small landowners one needs to distinguish between biomass chipping and small hand chippers. Most small landowners visualize chipping with a small chipper and do not understand what biomass chipping is. The difference between commercial biomass chipping for power cogeneration and small chipping for example defensible space around a structure needs to be recognized.

V-Blading

Tractors mounted with a V blade can be effective in mitigating high slash loads or for facilitating making planting sites in brush field conversions. The V blade casts the brush to the side exposing bare mineral soil that is ready to plant. In brush field conversions, it is best to kill the brush with an aerial application of an appropriate herbicide at least a year in advance of V blading as large green brush can be difficult to root out. It is possible to pull a single ripper shank behind the tractor if sub-soiling is a desired treatment. This method of site preparation is limited to level terrain and is difficult, if not impossible to do where there are many tree stumps.

Figure 7.7 V-Blade clearing landing slash for planting.

Spot Cultivator

One site preparation tool that has been used in California with some success is the VH Mulcher. This machine utilizes a spinning head with angled blades that not only crushes vegetation in a circular area about four feet in diameter, but mitigates compaction and creates planting spots for seedlings by tilling the soil. It is expensive and can run between $150 and $400 per acre depending on the number of planting spots created, density and size of brush, slope and rockiness. It crushes and grinds the vegetation creating fairly small spots, so it usually must be used with another form of vegetation control to be successful. The planting spots created are depressions in the soil that have been vigorously disturbed. Vegetation is usually slow to come back in the holes themselves, but encroachment from the edges is fairly rapid.

Figure 7.8 VH Mulcher Mounted on an Excavator.

Spyder

The spyder is another specialized form of mechanical site preparation equipment designed for piling slash on steep slopes. This equipment is capable of operation on slopes over 65% but gets more expensive as the slopes steepen. To keep the costs under control one must be careful to just make the site plantable and not overly clean the site. If piles created are burned, one must be very careful with the burning prescription. If one is not careful burning piles on steep slopes that are not cleaned they can easily turn into a broadcast burn. If one does plan to burn these types of units, it is highly recommended to put a fire line around them just in case the ignition turns into a broadcast burn.

Figure 7.9 Spyder site preparation machine.

Terracing

In the case of steep terrain, terracing has been used historically to primarily clear brush and occasionally logging debris to make planting sites. Terracing is done by using a tractor with a straight or angle blade to dig into the hillside and side cast organic material and soil downhill creating a nearly level surface. The terrace must be slightly out sloped and on the contour to facilitate proper drainage and minimize erosion potential. Creating terraces can be extremely expensive and cause adverse effects when topsoil is displaced and mixed, and the flat terrace surface may be less hospitable subsoil that can have long-term detrimental effects on productivity. For these reasons this once common site preparation method is rarely used in California.

Mounding

Mounding is used in high water table situations to create planting spots that are well-drained. This can be done with a VH Mulcher or an excavator. This is a very common practice in Canada but rare in California, usually used in areas around meadows or flats with high water tables. The problem is opposite in California, with planting usually in the bottoms of holes or sub-soil furrows to get closer to water.

Other

There are many forms or systems of equipment that can be used to accomplish various site preparation objectives. There is old equipment modified for various objectives and new equipment being developed all the time, be creative and give operators a chance. Some examples include: the tree planting excavator in Canada used to create mounds and plant trees at the same time, farm tractors mounted with large heavy-duty roto-tillers.

Manual

Manual vegetation control involves cutting, grubbing, pulling or some other method of physically removing vegetation by hand. These are usually associated with sensitive sites including; steep slopes, highly visible, urban-interface or other areas of concern.

Vegetation control using these methods is usually of short duration and application costs can be very high (Knowe 1992), and as a result, they are commonly used in combination with another method of vegetation control. Manual control of vegetation is particularly useful in areas that chemical application is not feasible, such as projects in close proximity to residential areas or in areas that may be sensitive to herbicide application due to multiple water courses and associated buffer zones. Other uses might be in very remote areas with limited access by application equipment where grubbing crews can provide a release treatment by hiking into the treatment site. Manual treatments are frequently used by the United States Forest Service (USFS) in their reforestation activities, at least, in part, due to the complex authorization process required prior to use of chemical treatments.

Grubbing

Grubbing is often used as vegetation control as an alternative to herbicides. Most often it is used as a release treatment but can be used as a site preparation method. Research done as part of release studies gives direction on the minimum and effective sizes of treatment. McDonald, Oliver and Fiddler with the Pacific Southwest (PSW) Research station have conducted many studies in northern California from the 1970's to the present focused on woody competition and effects on survival and growth. Early studies were summarized (McDonald and Oliver, 1983) comparing various grubbing techniques to herbicide treatments. It was statistically significant that when woody shrubs were greater than 20 to 30 percent of cover seedling and sapling growth is retarded. From early studies (Fiddler and McDonald 1984, McDonald and Fiddler 1989) the minimum effective radius is 5 feet, any lesser radius does not give the conifer seedlings time to develop the deep and extensive root system necessary to secure adequate soil moisture for growth at the potential of the site. These same studies found, the first 3 years are important; the first year is critical. Seedlings must be free to vigorously expand their root systems in an ever-increasing volume of soil. Results from Tesch and Hobbs (1989) with Douglas-fir showed roots expanded greatly in biomass and volume of soil occupied in the near-absence of competing vegetation, but developed scarcely at all if roots of competing species were present. McDonald and Fiddler (1990, 2010) found, grubbing 4 foot radii around ponderosa pine seedlings did not appear to be effective biologically and was expensive. Applying treatments at an early age led to statistically significant differences among treatments earlier than in other studies, and suggested the worth of treating competing vegetation as soon as possible. The two most intensive treatments in this study, Velpar herbicide and increasing the radii to 6 feet were the most effective. McDonald and Oliver (1984) found, the best treatment is one that not only effectively controls competing vegetation, but does so when conifer seedlings are becoming established.

A clear conclusion from these studies is that the minimum cleared radii for effective treatment is 5 feet. For smaller distances, the roots of the adjacent vegetation was able to access enough of the water and nutrients in the cleared area to impede the growth of the seedlings. Treating entire plot areas whether by grubbing or herbicide produce the best survival and growth. From a cost perspective, the grubbing is exponentially more expensive than herbicide. McDonald and Fiddler (1990) showed effective grubbing to 6 foot radii had labor costs $578/ac vs. a total cost of $152/ac ($38/ac for labor, $113 with chemicals) for Velpar. McDonald, Fiddler and Myer (1996) showed grubbing a 4 foot radii for 3 years was $420/ac and Velpar $102/ac. (the labor component was $27/ac.) McDonald and Fiddler (1995) found grubbing entire plot twice was $1,696/ac. compared to the labor cost of spraying Velpar of $27/ac.

Mulches and Mulching

Mulches used as a site preparation tool for the regeneration of conifers have been tested and applied commercially in many different forms. Paper, polypropylene fiber mats, plastics and many other sheet form materials have been used with varied results. The rational for applying mulch in these forms is to control competing vegetation and create a more favorable moisture environment for the seedlings. Studies have shown that the size of the mulch mat needs to be 10’x10’ to significantly enhance conifer seedling growth. (Fiddler and McDonald 1987) When using large size mats, it is important that the mats are made of a permeable material that allows moisture through to the soil below. These types of mulches have proven to be very expensive from a material and installation standpoint and generally less effective for control of weeds than chemical or manual weeding. Gophers and voles often find the mulch material a good place to take up residence and can cause damage to the seedlings. In high value areas such as in campgrounds or in park settings where use of herbicide may not be an option, these types of mulches may be a viable alternative. In large scale projects that generate slash and other organic debris, use of machinery to convert that material into organic “wood” mulch form may be feasible.

Hand Piling

Hand piles are often associated with slash disposal and fuels treatment in difficult areas like along roads and around structures particularly in the wildland urban interface (WUI). Small piles oven associated with defensible space are limited to 4'x4'x4' to allow rapid burning and control adjacent to structures. They can be used in small landscape areas where it's not cost effective to move in equipment or on steep slopes that will not allow equipment. Hand piling and burning is very expensive and risky due to liability of fire and usually limited to high value sensitive areas.

Biological

Biological control is achieved utilizing a naturally occurring organism or substance to control vegetation. Successful examples of biological control include control of tansy ragwort (*Senecio jacobaea*) using the Cinnabar Moth (Fuller 2002) and control of St Johnswort (*Hypericum perforatum*) with the Klamath weed beetle (Holloway 1964). Pathogenic fungi are also under investigation to control certain types of vegetation, but to date the results have not been as successful (Wall 1996, Wall & Shamoun 1990). Biological control methods are usually limited to very specific pests, which does not make them applicable to broad spectrum vegetation control. They are usually also restricted to certain geographic ranges or elevations. In most cases, biological controls are a small part of a larger management program (Newton & Dost 1984).

Burning

Fire is of the most common cultural treatments historically used to manage vegetation in forestry. But today with increasing constraints and regulations regarding air quality and smoke management along with general liability concerns, this practice is used much less frequently. Smoke management plans have also made burning more difficult in recent years. The number of burn days available are fewer to comply with Clean Air Act requirements. Historical uses of fire revolved around reducing post-logging slash and residual vegetation on site. Substantial gains in vegetation control have also been shown when burning is used in combination with herbicides (Powell 1992). Burning without the use of herbicides can actually release some fire adapted species such as deerbrush, snowbrush, blue blossum (*Ceanothus thyrsiflorus)* and knob cone pine (*Pinus attenuata*) (Weatherspoon 1987, Newton & Dost 1984).

Fire has been shown to increase conifer survival and growth, especially in combination with herbicides (Taylor et al. 1991). The authors looked at piling, broadcast burning and spraying, burning alone, all treatments with and without disking. Two years after treatment, the spray plus burning treatment had greater consumption of fuel compared to burning alone, and better vegetation control and seedling growth than either burning alone or the piling treatment.

Fire Behavior and Prescriptions

There are several disadvantages to using fire for vegetation management. The liability associated with burning is substantial. There is always the risk of escape and associated suppression costs. The importance of developing and following a detailed prescription for any planned fire is essential. Ten-hour fuel sticks are a valuable tool for monitoring fuel moistures to monitor fuel moisture inside and outside of units, an important prescription factor being the difference inside and outside the unit. Burn bosses must have a thorough understanding of fire behavior and weather. Weather conditions prior to during and after a fire are critical to success. Weather after a burn is not always adequately considered. Many problems with fires escaping are in the days after a fire when strong winds cause fires to escape before they are extinguished. Patrolling a fire and mopping up after fire is essential prior to any forecast wind events. The forester must also have the experience and ability to call off a potentially high risk burn when conditions are not right.

Broadcast Burning

Broadcast burning on steep slopes is one of the primary methods of burning to reduce fuel loads to make site plantable and facilitate follow up planting and spraying. One significant advantage of fire is adaptability to steep slopes where heavy equipment use is infeasible. The use of fire reduces difficulty for hand crews during subsequent planting, spraying and thinning, thereby, reducing costs (Newton & Dost 1984). Once the prescription is done it is important to prepare the unit for burning. A key step is creating an adequate fire line to contain expected fire behavior. Often this is best done by the logger while on site if they have the proper equipment rather than moving equipment in just to build fire line. Sometimes there is slashing work or chemical application to kill brush that helps create conditions that allow fuels to dry faster than adjacent fuels to allow a fuel moisture differential that facilitates burning the unit while it is dry and adjacent ground is still wetter. This helps prevent fire spotting and escapes. Another practice to reduce risk of escapes is "black lining" the top of the unit before lighting the rest of the unit. By burning a strip off the top of the unit and letting it cool down, it effectively widens the fire line at the top of the unit.

Figure 7.10 Broadcast burning.

Another key factor to facilitate safe burning is access. It is essential to have good access for equipment especially water tenders and fire trucks to the top of a unit in case of an escape. Getting personnel and equipment to a spot fire in a timely manner facilitates control in a timely manner. This is another instance when working with the logging administrator is advisable. In preparation for burning it is important that the logger does not block off roads or water bar them so extensively that a water truck cannot access the unit.

During ignition operations, it is imperative to have adequate personnel and equipment available to accomplish ignition and containment. One way to limit the number of personnel needed is to do ignition with a helicopter. This can be riskier from the perspective of generating too much fire too fast and increase the risk of escape. The benefit is not having to expose burners to the risk of lighting the fire by hand and its risks to rollers, falling, and dehydration. There are additional logistics involved but if there are several burn units in a localized area this is a way of getting more done to take advantage of narrow and infrequent burn windows.

Pile Burning

Burning piles can take on many forms such as hand piles, tractor piles or windrows and landing piles. Each has its own pros and cons. As with all fire, liability is becoming a greater concern and limitation. Like broadcast burning it is important to monitor piles after they are burned until they are out and mop up if necessary, if high winds are forecast and piles are not out. A wise tactic for preparation of all burn piles is to cover them or at least a portion of them with some waterproof cover. This is especially true of small hand piles and landing piles. This facilitates burning piles during wetter, safer conditions by creating a dry portion in the pile to assist with ignition. The temptation can be to wait until things are very wet, but usually it is better to burn a little earlier (but after adequate precipitation) to get more complete consumption. Poor consumption can lead to hold over piles that rekindle in the spring. Large landowners are more acceptable of marginal fuel consumption. If burning on small landowners, they normally expect much cleaner sites upon completion. If there are large units to burn with large piles it is advisable to contain the piles with a fire line prior to burning to help avoid escape.

Hand piles have the advantage of being small, burn down rapidly and go out faster. But if one lights too many piles and they are not out before a major wind event they can still be a problem. Tractor piles are large and can burn for days, weeks or months depending on how much dirt ends up in the piles that may bury large fuels that can smolder for a long time. When piling brush, it is often difficult to avoid getting dirt in the pile, especially with species like chinquapin that has an extensive root system. The best way to try and reduce dirt in a pile is uproot the brush throughout a unit and then go back and finish the piles. This allows the brush and soil some drying time to enable some dirt and finer foliage to fall off as the material is moved into completed piles. This accomplishes getting less dirt in piles and leaving some of the nutrient rich vegetation on site, providing some organic material for erosion control. Avoid the temptation to create completed piles as you go.

A technique being used for logging slash in conjunction with whole tree logging is to shear the material with hot saws and then skid sheared bundles to landings for concentration or to scattered piles in a unit. Compared to pushing sub-merchantable material into pile with a brush rake, this technique has the advantages of fewer piles to burn, cleaner piles with less dirt in them, and s cleaner and faster pile burns. Excavator type loaders from logging are used to stack the piles to facilitate larger and fewer piles. Individual sheared bundles usually do not burn that well, so it is better to combine the bundles to get better burn conditions and consumption.

With whole tree type logging landing piles can be very large if biomass markets do not exist. To provide for a safe burn it is critical that the piles not be pushed up against green residual trees that are meant to be saved. Since these piles can generate tremendous amounts of heat, a wide fire line around the pile is essential to contain large piles while burning and from radiant heat. It is most efficient to build the fire lines when the appropriate logging equipment is on site. Working with the logging administrators is critical to getting the appropriate fire lines constructed economically.

Large landing piles generated from chipping residue can be particularly problematic. These piles potentially have a lot of small organic debris and soil in them and not much air space making burn consumption poor. If they are built with a landing cat instead of a grapple loader they can have a lot of dirt in them, which reduces the degree of burn consumption. Large landing piles take a long time to burn and need to be monitored in the spring to make sure they are out. An alternative is to skid this residue material back out and scatter in the harvest unit as it is being generated. This material is often nutrient rich and good for long-term productivity. It's important that it is not spread to thickly so it can be planted through and spread to areas beyond the landing.

Figure 7.11 Top and Landing pile burn.

Worker Safety during Fires

Prescribed fire can also expose workers to a wide variety of toxic byproducts such as methanol, acetic and formic acid, dioxins, terpenes, tars, xylene, benzene and others (Newton & Dost 1984). Another safety factor is the exposure of workers to rolling debris coming out of a fire that may not be seen coming out of the smoke. Rollers can also be a danger during holding and mop up operations. Walking through thick slash with a drip torch is a risk to tripping and falling and getting hurt, hydration is also a risk during hot and strenuous conditions.

Cutting, clearing and walking fire-lines on steep slopes can also be dangerous, although, Kauffman (1992) demonstrated that the incidence of worker injury and worker's compensation claims during post burning activities such as planting, backpack spraying and thinning was less on units that had been broadcast burned compared to units with heavy slash and brush loads.

Cultural

Cultural treatments are management practices that have a direct or indirect effect on vegetation control and can take on many forms. They can be land management activities such as burning (already covered in depth in this chapter) or grazing that can affect competing vegetation itself, or seedling development programs such as seedling nutrition or stock type selection to enable seedlings to outcompete the vegetation. There are many concepts and ideas that can be incorporated into a management program to minimize vegetation management inputs. Like some of the other methods of vegetation control, cultural treatments are only a part of an integrated approach for vegetation management.

Chemical

Chemical site preparation is focused on controlling competing vegetation by treating it prior to planting. There are two main types of chemical site preparation: pre-harvest and post-harvest. Each can be accomplished with a variety of methods either broadcast or directed, using hand applications or aerial. More detail is covered in chapter 9. Chemical vegetation control involves the use of herbicides, desiccants or growth regulators to control unwanted vegetation. The overwhelming majority of chemical vegetation management is done with herbicides and therefore will be the predominant method discussed in this text. Herbicides are generally the most effective and efficient method of vegetation control. Herbicides and their application methods have been the focus on decades of technological improvement as well as state and federal regulations to ensure a very high margin of safety and methods to mitigate specific concerns (Newton & Dost 1984).

Pre-Harvest Site Preparation

This has become very common in recent years because it is so effective since imazapyr was registered in California. It is a particularly effective method and chemical for hard to control woody species. Due to conifer tolerance issues, there are many more chemicals that can be used in a site preparation situation than in a release. Treatment cost in a site preparation circumstance is much cheaper than in a release when trees must be protected. The need for follow up release treatments is also reduced, which is an additional cost savings. The added benefit of reduced release expense is an overall reduction in chemical use. The two primary methods of site preparation application are 1) foliar for applications to brush species and 2) hack and squirt application for hardwood tree species. Hack and squirt is particularly helpful with hard to control hardwoods, such as tanoak on the coast. Logistical planning and coordination with Timber Harvest Plans (THP's) is important. Plans need to be done at least a year before logging to allow time to do pre-harvest treatments soon enough before logging to allow for chemical to work and to allow loggers and other non herbicide applicators to freely work on the site without special post herbicide application requirements. Treatments should be done at least two months before logging and ideally at least one year, or through one winter, after treatment. Safety of fallers in heavy hardwood stands is a concern. Some fallers will not work in stands that have been treated too long before cutting as dead and brittle trees can experience considerable limb breakage during falling that can be dangerous.

Post-Harvest Site Preparation

Prior to the registration of imazapyr in California postharvest chemical site preparation sprays were the most common type of application and for post-wildfire it is still widely used. A problem with post-harvest treatments is that the vegetation is frequently damaged during the logging process and goes into shock making the application less effective. Sometimes with hard to control woody species it can be advantageous to wait and control them after they have had time for crowns to recover as foliar herbicides are most efficacious on actively growing plants. It may be necessary with re-sprouts to wait two-three years for re-growth to occur for above ground leaf area to match the below ground root system to allow for better chance of control. If using imazapyr to control hard to kill woody species post-harvest, it may mean waiting at least one year depending on soil types and precipitation, to avoid root uptake of imazapyr by seedlings, ponderosa pine is particularly susceptible to damage.

No matter whether you treat the woody species pre or post-harvest, the grass and herbaceous species still need to be treated. In the first year after planting it is the grass and forb community that poses the biggest risk to survival of seedlings. Treatments for herbaceous weed control include pre-plant broadcast treatments and post plant directed sprays. Broadcast treatments of hexazinone, oxyfluorphen, penoxsulam or other soil active herbicides can prevent emergence of competing herbaceous species and are the best alternative available. If no pre-plant application is made and grasses emerge after planting, a directed spray will be necessary for survival. See chapter 9 for more in depth discussion on chemical site preparation options.

Brushfield Conversion

Converting brush fields that result from old burn scars can be a unique challenge for preparing the site for planting. Because of the presence of large amounts of living brush on the site a combination of treatments are necessary. Removing the brush can be done mechanically by rooting out the green brush with a Cat tractor equipped with a brush rake. The most common way to achieve this is to push the brush into windrows and allow it to dry for a few weeks. After this drying time, the brush will need to be moved in a way that releases the soil held by the roots and the clean brush piled in burn piles.

Another method of conversion is to spray the brush well ahead of the anticipated planting date. Herbicide applications will need to be done with a helicopter or fixed wing aircraft because ground access will be impeded by brush. Fixed wing applications are only suited for flatter terrain and herbicide options are more limited than with helicopter applications. Once the brush is dead and brittle, many mechanical options are available to prepare the site for planting. Good results can be achieved through crushing/tilling, mastication, v-blading or broadcast burning.

Figure 7.12 Sprayed brush crushed and planted in dozer tracks.

Summary

Good site preparation is a critical step to establishing a successful plantation. Evaluating the site as discussed in chapters 3 and 4 is imperative for identifying potential limiting factors on site and develop a prescription to create desired conditions to encourage survival of planted seedlings. Applying a combination of site preparation methods in a timely combination is necessary to achieve the best results. Effective and economical site preparation is an integration of science and experience to anticipate problems and mitigate them in a timely manner. Prevention is more effective and economical than having to do additional treatments after a problem develops. Years of experience have shown that the best money spent in reforestation is on good site preparation.

Figure 7.13 Well prepped unit with retention islands and cedar seed trees.

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References

Achat, D. L, et. al. 2015. Quantifying consequences of removing harvesting residues on forest soils and tree growth – A meta-analysis. Forest Ecology and Management. 348, 124-141

Arno, S.F., Smith, H.Y. and Krebs, M.A. 1997 Old Growth Ponderosa Pine and Western Larch Stand Structures: Influences of Pre-1900 Fires and Fire Exclusion INT-RP-495 USDA Forest Service Ogden, UT.

Arno, S.F. 1996 The concept: Restoring ecological structure and process in ponderosa pine forests. In: *The use of fire in forest restoration. Gen. Tech. Rep. INT-GTR-341*. C.C. Hardy and S.F. Arno (eds). U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, UT, pp. 37-38.

M. M. Atkinson & S. A. Fitzgerald, 2002. Successful Reforestation: An Overview. EC 1498. Oregon State University Extension.

Busse and Zhang, personal communication 2018

Certini, Giacomo. (2005). Effects of fire on properties of forest soils: a review. *Oecologia*, *143*(1), 1-10. doi: 10.1007/s00442-004-1788-8

Cleary, Greaves & Hermann, 1978. Regenerating Oregon's Forest, Oregon Cooperative Extension.

DeBano, L. F. (2000). The role of fire and soil heating on water repellency in wildland environments: a review. *Journal of Hydrology, 231-232*, 195-206. doi: https://doi.org/10.1016/S0022-1694(00)00194-3

DiTomaso, Joseph, Et. al, 1997. Post-fire herbicide sprays enhance native plant diversity. California Agriculture, Vol. 51, No. 1.

Fiddler, Gary O., McDonald, Philip M. 1984. Alternatives to herbicides in vegetation management: a study. In: Proceedings, 5th Annual Forest Vegetation Management Conference, pg. 115-126

Haig, I.T., Davis, K.P. and Weidman, R.H. 1941 Natural regeneration in the western white pine type. Tech. Bulle. 767. U.D.o. Agriculture (ed), Washington, D.C. , p. 99.

Helgerson, O.T. 1990. Heat damage in tree seedlings and its prevention. New Forests 3:333-358.

Hobbs, Tesch, et. al, 1992, Reforestation Practices in Southwest Oregon and Northern California.

Hudson B., 1994. Soil organic matter and available water capacity. Journal of Soil and Water Conservation, 49(2):189-194

James, Cajun E., & Krumland, Bruce. (2018). Immediate Post–Forest Fire Salvage Logging, Soil Erosion, and Sediment Delivery. *Forest Science, 64*(3), 246-267. doi: 10.1093/forsci/fxx013

Kauffman, J.B. 1992. Prescribed Fire in Forest Vegetation Management: A Research Synthesis. Proc. Forest Vegetation Management Without Herbicides. Oregon State University. Corvallis, Or. Feb 18-19. pp 25-28.

Knowe, S. A. 1992. Manual Techniques for Managing Woody Competition: An Overview. Proc. Forest Vegetation Management Without Herbicides. Oregon State University. pp. 90-91.

McDonald, Phillip M., and Oliver, W.W., 1983.Woody Shrubs Retard Growth of Ponderosa Pine Seedlings and Saplings. In proceedings of 5th Annual Forest Vegetation Management Conference, pg. 65-89.

McDonald, Phillip M., and Fiddler, Gary O., 1990. Ponderosa Pine Seedlings and Competing Vegetation: Ecology, Growth, and Cost. PSW-RP-199.

McDonald, Phillip M., and Fiddler, Gary O., 1995. Development of a Mixed Shrub Ponderosa Pine Community in a Natural and Treated Condition. PSW-GTR-224.

McDonald, Phillip M., Fiddler, Gary O., and Meyer, Peter W., 1996. Vegetation Trends in a Young Conifer Plantation after Grazing, Grubbing and Chemical Release. PSW-RP-228.

McDonald, Phillip M., and Fiddler, Gary O., 2010. Twenty-Five Years of Managing Vegetation in Conifer Plantations in Northern and Central California: Results, Applications, Principles, and Challenges. PSW-GTR-231.

Newton, M. and F.N. Dost. 1984. Biological and Physical Effects of Forest Vegetation Management. Final Report, Washington Department of Natural Resources. 423 P.

Peterson, David W., Paul F. Hessburg, Brion Slater, Kevin M. James, Matthew C. Dahlgreen, John A. Barnes, 2007 Reintroducing fire in regenerated dry forests following stand-replacinc wildfire. In: Powers, Robert F., tech. editor. Restoring fire-adapted ecosystems: proceedings of the 2005 national silviculture workshop. Gen. Tech. Rep. PSW-GTR-203, Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture: p. 79-86.

Ponder Jr, F., et. al. 2012. Effects of organic matter removal, soil compaction and vegetation control on 10th year biomass and foliar nutrition : LTSP continent-wide comparisons. Forest Ecology and Management. 278, 35-54.

Powell, R. L. 1992. Prescribed Fire for Conifer Regeneration in the Oregon Coast Range. Proc. Forest Vegetation Management without Herbicides. Oregon State University, Feb 18-19. pp.33-38.

Powell, J., J.F. Stritzke, R.W. Hammond, and R.D. Morrison. 1982. Weather, soil and 2,4-D effects on tallgrass prairie on Oklahoma. J. Range Manage. 35:483-488. *(PDF) Late-Summer Fire and Follow-Up Herbicide Treatments in Tallgrass Prairie*. Available from: https://www.researchgate.net/publication/252067713_Late-Summer_Fire_and_Follow-Up_Herbicide_Treatments_in_Tallgrass_Prairie [accessed Dec 13 2018].

Ritchie, M. W., and Knapp E. E., 2014. Establishment of a Long-Term Fire Salvage Study in and Interior Ponderosa Pine Forest. Journal of Forestry, 112(5) 395-400.

Taylor, S.W., B.C. Hawkes, R.H. Silversides and M.G. Weber. 1991. Initial Effects of Prescribed Fire and Mechanical Site Preparation on Seedling Environment and Establishment on a Backlog NSR Site in Central Interior British Columbia. FRDA Report #177. B.C. Ministry of Forests. Canadian Forest Service. 29 P.

Tesch, Steven D., Hobbs, Steven D. 1989. Impact of shrub sprout competition on Douglas-fir seedling development. Western Journal of Applied Forestry 4(3): 89-92.

Thompson, J.R., Spies, T.A. and Olsen, K.A. 2011 Canopy damage to conifer plantations within a large mixed-severity wildfire varies with stand age. *Forest Ecology and Management*, 262 (3), 355-360.

Weatherspoon, P. C. 1987. Prescribed Burning for Vegetation Management: Effects on *Ceonothus velutinus* Seeds in the Deff and Soil. Proc. 9th Ann. Forest Vegetation Management Conference. Redding, Ca. pp. 125-141.

Weatherspoon, C.P. and Skinner, C.N. 1995 An Assessment of Factors Associated with Damage to Tree Crowns from the 1987 Wildfires in Northern California. *Forest Science*, **41**, 430-451.

Zhang, J., Busse, M. D., Young, D. H., Fiddler, G. O., Sherlock, J. W., & TenPas, J. D. (2017). Aboveground biomass responses to organic matter removal, soil compaction, and competing vegetation control on 20-year mixed conifer plantations in California. *Forest Ecology and Management, 401*, 341-353.

Other Sources of Information

Mike Mitzel, personal comm.

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Chapter 8:
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The Influence of Competing Vegetation in Forestry

The focus of this chapter is primarily on the use of chemicals to control competing vegetation both before and after the conifer seedlings are planted. Mechanical, fire, and managed intensive grazing approaches to controlling competing vegetation can also be used in combination with chemical methods or as a substitute method. These methods are typically more expensive per acre and often do not achieve the same level of control of competing vegetation.

Competition

The success of forest regeneration depends on many things. In California's Mediterranean climate, the most critical factor which influences the success or failure of establishing a new forest is competing vegetation (Powers 1999). Competing vegetation can and will deprive newly established conifer seedlings of valuable light, nutrients and most importantly, water (White & Newton 1989). In California, where summer temperatures can exceed one hundred degrees, relative humidity may be in the single digits and long periods without rainfall are common, competing vegetation in excess of just twenty five percent cover may be enough to influence growth and survival of first year seedlings (Oliver 1984).

Pioneer brush species and hardwoods inherently grow faster than conifer seedlings and can quickly over-top planted trees depriving them of valuable light needed for photosynthesis (McDonald & Abbott 1997). Herbaceous vegetation in the form of grasses and forbs has adapted to capitalize on early available soil moisture for growth, and can quickly deplete available water for seedlings (White, Witherspoon & Newton 1990). It is important to realize that any vegetation other than the planted conifers are utilizing light, nutrients and water that are required for successful establishment of new seedlings.

The impacts of competing vegetation on conifer seedlings have been well documented. Ponderosa pine (*Pinus ponderosa*) survival was dramatically increased by controlling bear clover (*Chamabatia foliolosa*). Tappeiner & Radosevich (1982) demonstrated that in areas where bear clover was not controlled, ponderosa pine survival ranged from six to twelve percent survival compared to eighty to one hundred percent where it was removed. The same study also predicted wood volume losses of 75 percent by age 50 if bear clover was not controlled. Fisk (1984) also estimated volume losses of up to 70 percent in mixed conifer forests where bear clover was not controlled. Oester et al. (1995) showed survival increased from 18 percent to 63 percent and stem volume increased from 39 cubic centimeters to 819 cubic centimeters in ponderosa pine five years after planting from a single application of hexazinone compared to untreated controls in northeastern Oregon. In a study by White & Newton (1989) ponderosa pine growth was substantially reduced by manzanita ground cover as low as 20 to 30 percent. Powers (1999) showed a threefold gain in stem volume averaged over all sites using herbicides compared to the non-treated controls eight years after treatment in the Garden of Eden Study. Ponderosa pine growth was reduced by 80 to 90 percent three years after planting when greenleaf manzanita cover reached 50 percent (Radosevich 1984).

Controlling competing vegetation is most important early in the life of a new forest. McDonald & Fiddler (2001) showed that delaying release treatments until four years after planting and then treating each year for the next three years did not significantly increase growth over the non-treated controls. Small trees that received release treatments during the first three years after planting were statistically larger McDonald & Fiddler (2001).

Fuel Loading and Fire Risk

A secondary reason to manage competing vegetation is to maintain a relatively fire resistant landscape. When woody brush goes unchecked, it can quickly outgrow planted conifers. Usually one or two species will dominate a site and suppress others. Heavy fuel loads accumulate and plant biodiversity is also reduced (DiTomaso et al. 1997). Radosevich (1984) showed that greenleaf manzanita (*Arctostaphylos patula*) biomass on a good site one year after planting was almost 60 times that of ponderosa pine seedlings. One year after planting a site that had been mechanically site prepped, greenleaf manzanita plant density consisted of 123,500 seedlings per acre. During the ten year study, manzanita plant numbers decreased, but foliar cover increased by 21 times while height increased by seven times (McDonald & Fiddler 2001). As the average investment by private landowners to establish new forests is around five hundred dollars per acre, managing the vegetation to reduce fire risk is critical. Fire proofing a stand is impossible, but by managing the density and size of vegetation the intensity of the fire may be lowered to allow survival of the stand.

Environmental Considerations

Herbaceous and woody vegetation do have positive benefits and are an important but minor component of most reforestation projects in California. They provide habitat and food for wildlife, protect water quality, increase soil stability and can provide some aesthetic qualities to the landscape. It is very important as a land manager to realize that effectively treating vegetation to establish a new forest produces a very short-term effect on the landscape. Vegetation rebounds very quickly and by not letting one or two species dominate a site, plant biodiversity and species richness increase in the long-term (DiTomaso et al. 1997). How one manages vegetation depends on the landowners objectives. Goals for wildlife, water quality, soils and aesthetics can be easily integrated into a management plan. The ability to recognize where, when and how special vegetation management considerations need to be addressed is critical to sound and responsible planning. Specific concerns will be addressed later in this text.

The chemical control of competing vegetation is tightly regulated in California and commercial application in limited to licensed professionals who must follow the latest regulations.

Choosing a Method of Vegetation Control

Choosing a method of vegetation control should not be taken lightly. Failure has significant ramifications that are enormous from both a financial and biological perspective. The inherent cost of treatment and the potential cost of failure should provide the incentive to choose wisely and do it right the first time. So what should be considered in choosing a method of vegetation control?

It is imperative that foresters fully understand the treatment objectives before starting. Site preparation treatments for conifer establishment are usually much more intensive than managing vegetation for wildlife or recreation to achieve the primary goal of fast growth of the desired set of newly planted trees. The land management objectives and constraints will dictate what methods are suitable and which are not. Land managers must have a clear understanding of the desired outcome in order to evaluate effectiveness of the components of their work.

The budget is a very important consideration. The greatest savings can be achieved by doing things right the first time. Vegetation treatments are inherently expensive. Some treatments cost much more than others and may be less effective. It is important to consider both present and future treatment costs. Are repeat treatments going to be necessary? Will the treatments be mechanical, chemical or manual?

Another question involves the duration of desired control. Manual and mechanical treatments generally provide short-term control, while certain herbicide prescriptions can provide control over a number of years. There are exceptions to the short term impacts of manual and mechanical treatments. Large whiteleaf manzanita (*Arctostaphylos viscida*) for example, re-sprouts very little when disturbed. If it is too large to treat chemically, mechanically piling or masticating may provide satisfactory control.

One of the most important things to be aware of when deciding on a treatment option is the surroundings. Are there any sensitive areas around that may preclude the forester from using one type of treatment over another? The presence of sensitive water courses or wells, property lines, neighbor issues, or endangered species are all things that may influence the decision on which type of treatment to use. The crop species tolerance to herbicides may be an issue that dictates using another method of control. For example, if a particular conifer species is intolerant to available herbicides, manual or mechanical removal may be a better option.

Worker safety may be an important issue that influences the selection of a method. Slope, rockiness, temperature and access may all be safety issues that favor one type of treatment over another. Newton &

Dost (1984) showed through medical records that the risk of worker injury was magnitudes greater with manual removal treatments when compared to hand applied chemical applications.

There is a wealth of knowledge available to landowners regarding all types of vegetation control depending on the resource professional. Generally, foresters that work for private industry, consulting foresters, pest control advisors, licensed applicators and university personal work more with chemical vegetation management than state or federal employees. State and Federal employees tend to rely more on non-chemical vegetation control than private and have a vast amount of experience with alternative treatments. County offices of the Department of Agriculture as well as the Department of Pesticide Regulation can also provide valuable information. Consulting with vegetation management professionals will save the landowner valuable time and money as well as ensure a successful application to achieve the desired objective.

Methods of Vegetation Control

There are many different methods for controlling unwanted vegetation, and the selection of the desired method is a keystone in the success of the reforestation project. These various methods are introduced here and may be found in greater detail later in this chapter or within other chapters of this book.

Chemical

Chemical vegetation control involves the use of herbicides, desiccants or growth regulators to control unwanted vegetation. The overwhelming majority of chemical vegetation management is done with herbicides and therefore will be the predominant method discussed in this text. Herbicides are generally the most effective and efficient method of vegetation control. Today's herbicides and application methods also have a very high margin of safety and any specific concerns can be easily mitigated (Newton & Dost 1984).

Mechanical

Mechanical vegetation control is done utilizing some type of equipment to manipulate existing vegetation on a site. Piling, ripping and mulching are common examples. With subsequent weed germination or resprouting, mechanical vegetation control alone does not provide control in the long-term (Fiddler & McDonald 1997). As a result, mechanical vegetation control is usually done in combination with other methods of vegetation control such as chemical. Mechanical treatments may be especially appropriate where large brush or trees that cannot be treated by other methods is present, or where some type of soil amelioration may be desired.

Manual

Manual vegetation control involves cutting, grubbing, pulling or some other method of physically removing vegetation by hand. Vegetation control using these methods is usually of short duration and application costs can be very high (Knowe 1992), and as a result, they are commonly used in combination with another method of vegetation control. Manual control of vegetation is particularly useful in areas that chemical application is not feasible, such as projects in close proximity to residential areas or in areas that may be sensitive to herbicide application due to multiple water courses and associated buffer zones. Other uses might be in very remote areas with limited access by application equipment where grubbing crews can provide a release treatment by hiking into the treatment site. Manual treatments are frequently used by the United States Forest Service (USFS) in their reforestation activities, at least, in part, due to the complex authorization process required prior to use of chemical treatments.

Biological

Biological control is achieved utilizing a naturally occurring organism or substance to control vegetation. Successful examples of biological control include control of tansy ragwort (*Senecio jacobaea*) using the Cinnabar Moth (Fuller 2002) and control of St Johnswort (*Hypericum perforatum*) with the Klamath weed beetle (Holloway 1964). Pathogenic fungi are also under investigation to control certain types of vegetation, but to date the results have not been as successful (Wall 1996, Wall & Shamoun 1990). Biological control methods are usually limited to very specific pests, which does not make them applicable to broad spectrum vegetation control. They are usually also restricted to certain geographic ranges or elevations. In most cases, biological controls are a small part of a larger management program (Newton & Dost 1984).

Cultural

Cultural treatments are management practices that have a direct or indirect effect on vegetation control and can take on many forms. They can be land management activities such as burning or grazing that can affect competing vegetation itself, or seedling development programs such as seedling nutrition or stock type selection to enable seedlings to outcompete the vegetation. There is virtually an endless stream of concepts and ideas that one can incorporate into a management program to try and minimize vegetation management inputs. Like some of the other methods of vegetation control, cultural treatments are only a part of an integrated approach for vegetation management.

Non Chemical Weed Control Methods

Mechanical Weed Control

Mechanical operations in forestry are not always solely for the purpose of weed management. Mechanical treatments may have multiple objectives included mitigating compaction, improving water absorption, facilitating planting, slash removal, thinning or vegetation management. Mechanical treatments are also not usually used alone, but are one part of a larger program (McHenry 1982).

The majority of the discussion of mechanical site preparation treatments as they refer to aspects other than vegetation will be discussed in the site preparation chapter of this manual. We will briefly discuss the benefits associated with vegetation removal here. Mechanical vegetation removal can be an important part of the reforestation program and will usually have a significant impact on future treatments regarding cost, quality and accessibility.

Biomass removal

Removal of unwanted vegetation may start before the logging operations are even completed. When markets allow, one of the most important mechanical treatments foresters can do is biomass removal or chipping. The ability to chip unwanted material in the woods has several advantages. Fuel loading is drastically reduced as unwanted material is chipped and hauled off site. The costs of piling and potentially slashing after logging are drastically reduced or not needed at all. Poor quality sub-merchantable conifers can be easily and efficiently removed. Accessibility for planters, spray crews, and other reforestation efforts is improved. While the chipping treatments won't provide long-term control of the competing vegetation that is removed, it does bring it down to a manageable level. Future entries for chemical, hand or mechanical treatments will be much easier and more cost effective.

Piling

Depending on the slash load and component of large woody brush or sub-merchantable conifers following logging operations, reforestation units may need to be piled to improve access, remove residual vegetation and facilitate planting operations. Weed control by piling is primarily through the removal of large brush. In many cases, large plants such as manzanita can be entirely pulled or pushed from the ground root systems and all. This can control some plants where the entire plant system can be removed. In other cases the brush is too small or flimsy to be entirely removed and control must rely on some other method. If pre-sprayed prior to harvesting, much of the brush is dead by the time piling occurs, and it can be easily crushed or piled. This also reduces the amount of time needed for piles to dry in preparation for burning.

Piling operations can be conducted with several different types of equipment. Bull dozers are the primary method used. All bull dozers utilized for piling should be equipped with brush rakes to minimize the amount of soil disturbance.

Excavator piling is another option that has several additional benefits. Much less of the ground is covered by the tracks of an excavator compared to a bull dozer due to the reach of the boom, and as a result, potential compaction is lessened. Using the grapple of the boom, large brush and woody sprout can be pulled from the ground minimizing movement of topsoil. Furthermore, steeper slopes can also be reached with an excavator, often times up to 40 percent.

Piling costs when using tractors in logging units usually range between $150 and $250 per acre for logging units, but the use of excavators is more expensive and can add another $50 to $100 to the per acre cost. If converting old brushfields, piling costs are usually higher when dense and large old brush is present that must be removed prior to any other activity. It has become less popular to utilize piling for site preparation. Increased opportunities are now available to avoid the cost and disruption of piling. These include chemical pretreatment and planting through resultant slash and creating micro-sites for conifer seedlings with equipment that does not operate over the entire unit's surface area. In addition, poor piling practices can impact site quality through excessive soil disturbance. Finally, the liability when burning piles or windrows created by this method is a risk many landowners are now unwilling to accept.

Sub-soiling

Site preparation treatments with sub-soiling utilize a bulldozer fitted with a brush rake and a series of steal shanks fitted with slightly angled wings on each side of the shank. The shank and wings are designed to rip, lift and drop the soil to mitigate compaction. A secondary result of the treatment is that it disturbs any remaining vegetation it comes in contact with.

One of the largest environmental studies in the history of the United States is the Long Term Soil Productivity Study (LTSP) which is installed on many sites across the country (Powers & Fiddler 1997), with twelve sites installed in California. The study looked at several factors affecting conifer survival and growth including compaction, vegetation management and soil organic matter. Treatments consisted of light, moderate and heavy compaction, with or without vegetation, and organic matter removed or present. The LTSP study has been in existence since 1989 and occurs over a wide range of conditions and soil types across the country.

Regarding the sub-soiling effect on vegetation, the results vary by site but on the Challenge, California site some interesting results occurred. At the end of the fourth growing season the average ponderosa pine volume increment was greatest in the compacted plots and least in the lightly compacted treatments that were sub-soiled in two directions. This seems counter intuitive, but it is because of the competing vegetation this occurred. Vegetative cover averaged 56 percent in the compacted plots and 91 percent in the sub-soiled plots. Less weed cover translates to increase moisture availability. When the effect of vegetation was removed, the sub-soiled plots were clearly superior to the compacted ones (Powers 1997). Potter (1984) also showed that when units with bear clover present were ripped, rhizomes were broken up and spread across the unit resulting in even more of an infestation. This result seems to heavily rely on the type of vegetation present. Others have shown very positive growth responses on ponderosa pine to sub-soiling (Helms et al. 1986, Froehlich & Robbins 1983).

Mastication

Mastication involves crushing or grinding vegetation on site with some type of specialized head mounted on a piece of heavy equipment. This method of vegetation control is expensive, but negates the need to follow-up piling. Organic mulch that is left on site may also increase the water holding capacity of the soil (Hudson 1994). It is a good method to use when vegetation is large enough to hinder reforestation efforts and can sometimes be used in place of broadcast burning. Masticating the vegetation will not kill re-sprouting species, and as result, it is best used in combination with herbicides for effective control. Recently, dense stands of 60 year old tanoak regrowth in the Sierras have been operationally treated using this method. Trees were severed and laid on the ground with a feller buncher and then masticated. This created a relatively thick layer of shredded organic matter that could be picked through for planting spots, albeit with some difficulty. While this operation was expensive, ranging from $400 to $500 per acre, it created an opportunity for recapturing hardwood-dominated, high site timberland that would otherwise have required heavy equipment clearing and high risk burning, if even possible at all. As mentioned earlier, the resultant fuel loading during the early years of the plantation must be considered, and the presence of re-sprouting species would require the consideration of a site preparation spray as part of the prescription.

One masticating site preparation tool that has been used in the past, but now with relatively limited availability, is the VH Mulcher. This machine utilizes a high-torque spinning head with angled blades that is ground down into the soil. In so doing, it not only masticates vegetation in a circular area about four feet in diameter, but also alleviates surface compaction and creates planting spots for seedlings. It is expensive and can run between $250 and $400 per acre depending on the number of planting spots created, density and size of brush, slope and rockiness. This method generally does not preclude the need for herbicide treatment of the surrounding terrain, as encroachment from the edges can be fairly rapid. Care should be taken in some soil textures as the vigorously disturbed planting spots may initially have a high percentage of macro pores that can impact root growth.

Using masticating heads on a maneuverable boom can reduce residual damage to the conifer plantation. Where large brush is present in established plantations, mastication can be used as an effective release tool by reducing brush competition at the same time as pre-commercially thinning existing conifers to desired levels. Release treatments such as these usually occur in older plantations, where brush has been allowed to dominate and is too large for any type of manual treatment.

Fiddler and McDonald (1997) compared different mechanical release treatments in a 12 year old Ponderosa pine plantation which included a non-treated control, removing vegetation with a Hydro-Ax shear only, and removing vegetation with the shear followed by an application of 2,4-D to the re-sprouting vegetation the year after masticating. After 11 years, the Hydro-Ax plus the use of herbicide had significantly larger crowns, diameter and height than either the Hydro-Ax alone or the non-treated controls. The only difference between the hydro ax only treatment and the untreated controls was in crown volume. A study by Fiddler et al. (2000) showed similar results on a 16 year old ponderosa pine plantation using a Trac-Mac shear instead of a Hydro-Ax. The treatments consisted of a untreated control, Trac-Mac cut-only, and Trac-Mac cut plus a herbicide treatment with 2,4-D two years after cutting. Eleven years after treatment the Trac-Mac only treatments had no significant differences in crown volume, diameter or height compared to the non-treated controls, whereas the Trac-Mac plus 2,4-D treatment had significantly larger crowns than the untreated control or the Trac-Mac only treatment. Somewhat larger diameters and heights resulted from the Trac-Mac plus 2,4-D treatment, and while not significant, the authors did point out that growth rates were diverging over time between treatments.

All mechanical mastication methods are expensive and should be reserved for those situations where other options are limited or specific objectives have been identified, such as reduction of herbicide use or elimination of burning. When needed for release, the costs necessary to reclaim a site using mechanical methods emphasize the importance of adequate vegetative control in the first place.

Manual Weed Control Methods

An advantage of manual weed control is that these methods can be more socially acceptable and have fewer environmental constraints than other methods. Additionally, manual treatments can be highly selective and can even be incorporated into pre-commercial thinning programs. The disadvantages of manual treatments is that they require a large skilled crew, often result in more worker injuries, and are less effective than chemical methods (Newton & Dost 1984). The largest disadvantage is high cost and a very short duration of control (Knowe 1992).

Manual release treatments can include such treatments as hand grubbing, cutting, utilizing mulch mats, shade cards and other non-chemical control methods. Probably the most popular method of manual weed control is hand grubbing. Hand grubbing involves the manual removal of live vegetation through the use of hoes, shovels or other implements. Hand grubbing is usually done after the seedlings have been planted. To maximize effectiveness, treatments should occur after the large majority of vegetation has emerged in the late spring to early summer and should remove all root systems within the grubbed area to be effective.

Several studies have evaluated the results of hand grubbing. McDonald and Fiddler (1990) compared several sizes and intensities of hand grubbing treatments to a single application of Velpar L (hexazinone). Treatments included two and four foot scalps applied at age one, half of which were expanded to four and six foot scalps at age four. Four years after treatment, trees treated with the single application of Velpar L were significantly larger in caliper and height for all treatments except the four foot scalp that was expanded to six feet. No grubbing treatments had significantly larger calipers or heights than the non-treated controls other than the six foot radius scalp. Labor costs were high, however, with the six foot radius scalp treatment costing $578 per acre in 1984 dollars compared to $38 per acre for the single Velpar L treatment. With annually repeated grubbing treatments for the first three years after planting, McDonald and Fiddler (2007) did show increases in caliper and ponderosa pine leaf area compared to non-treated controls, but at a cost of $1890 per acre assuming labor rates of $28 per man hour.

While expensive, hand grubbing can be successful in achieving survival provided the scalps are large enough and the treatments are repeated when competing vegetation returns. In the absence of chemical vegetation control methods, the hand grubbing treatment is better than doing nothing.

Cutting brush or hardwoods with a chainsaw or hand saw is another manual method to release conifer seedlings. However, doing so without chemical follow up is a very short-term treatment. McDonald et al. (1989), showed that tanoak cut with a chainsaw was over-topping Douglas-fir seedlings four years after treatment. By nine years after treatment, Douglas-fir height was not significantly different from the non-treated controls, and only small gains in Douglas-fir diameter were achieved. D'Anjou (1990) found that when woody brush and hardwoods were cut, they reached 50 percent of their pre-treatment height by the end of the first growing season. The study also showed no brush mortality occurred as a result of cutting and timing of treatment had little effect. When compared to herbicide treatments, cutting provided significantly poorer control than glyphosate. Similar results were found by Simard and Heineman (1996), who showed that cutting had no effect on Douglas-fir caliper or height nine years after treatment, but treatments with glyphosate significantly increased diameter. The same study on a different site showed significantly larger diameters on lodgepole pine for the cutting and glyphosate treatment compared to non-treated controls nine years after treatment. Whitehead and Harper (1998), compared four types of vegetation control for release of Engelmann spruce including treatments with glyphosate, 2,4-D, manual cutting and a non-treated control. Ten years after treatment, the glyphosate treatments were the most effective in reducing brush cover and height and significantly reduced the height to diameter ratio and competition index. All other treatments failed to meet Canada's minimum stocking standards at the completion of the study. Mixed results on conifer growth have been found by others. Pendl and D'Anjou (1990) found no growth response from grand fir but height growth in Douglas-fir was significantly increased five years after cutting.

If cutting is to be done, some of the literature suggests it is better to cut woody brush and hardwoods later in the season when carbohydrate reserves are low (Pendl & D'Anjou 1990). Increasing the frequency of cutting and cutting to the lowest stump heights possible may also reduce the amount of re-sprouting (Harrington & Tesch 1992), and cutting is much more effective when followed up with herbicides to reduce sprouting (Wagner & Rogozynski 1994). McDonald & Tucker (1989) concluded that cutting treatments are very expensive for a short-term reduction in cover.

Another manual method that has been used over the years is the use of mulch mats. Mulch mats can be made out of paper, plastic, polyester, asphalt or other durable material and range in size up to ten feet in diameter. The purpose of placing mulch mats around tree seedlings is to deprive competing vegetation of light, heat the soil enough to prevent germination and retain valuable soil moisture for tree seedlings (Haywood 1999). Mulch mats can be an effective method of control in certain instances but they are expensive, difficult to install, require maintenance to maintain their position around seedlings, are problematic with sprouting species and often don't degrade in a reasonable amount of time (McDonald & Fiddler 1992).

Early polyester mulch mats reduced the amount of vegetation around tree seedlings, but didn't significantly increase Douglas-fir diameter or height over the controls (McDonald & Fiddler 1992). It found that the mats didn't allow water to penetrate, creating desert like conditions for seedlings. As a result, the type of material used is extremely important, and subsequent studies found that Pac-Weave was the best available material that didn't constrict tree growth, reduce water penetration, degrade too fast and was easy to install (McDonald & Fiddler 1992, Craig & McHenry 1987).

Conifer growth responses from the use of mulch mats are mixed. McDonald et al. (1994), compared polyester and paper mulch mats to hand grubbing treatments annually repeated for five years. Five years after treatment on Ponderosa pine seedlings, the polyester mats and the hand grubbing treatments yielded significantly larger diameter and heights compared to non-treated controls. However, the cost of the mulch mats was $2072 per acre. Harper et al. (2005) found that mulch mats reduced the amount of herbaceous vegetation in the first three years, but they failed to significantly increase survival, diameter or height for Douglas-fir seedlings compared to non-treated controls. That is the opposite of treatments with either glyphosate or hexazinone in that study. Haywood (2000), found that both mulch and hexazinone treatments resulted intaller loblolly pine seedlings and caused them to grow out of the grass stage faster than the non-treated controls. Other studies by Haywood (1999) had mixed results regarding growth of loblolly pine.

Mulch mats may have some potential, but are expensive and require considerable labor to install. McDonald and Fiddler (1992) reported the cost of large mulch mats can be as high as $9.90 per seedling, severely limiting the number of seedlings that can be treated effectively. Land managers that choose to use mulch mats may just want to focus on treating only a certain number of crop trees to keep the costs down.

Manual vegetation control treatments will always have some fit in forest management. However, when used alone, results will be extremely short-term and are best used in combination with chemical treatments for lasting control. If chemical methods are not available, it is important to realize that repeated manual treatments will be necessary and costs will be high.

Biological Control Methods

Biological control of vegetation can be attempted by several different methods. Insects, pathogenic fungi and the use of allelopathic organisms are all methods of biological control. Very little is known about the latter two methods, but some gains have been achieved with the use of insects on species such as Klamath weed (St Johnswort), tansy ragwort and to a much lesser degree Mediterranean sage. (Fuller 2002, Isaacson & Brookes 1999). Currently, new biological agents are being tested for control of alligator weed, Cape ivy, Dalmation toadflax, gorse, musk thistle, Russian knapweed, Russian thistle, Scotch broom, tamarisk and yellow star thistle. Of these, the hairy weevil which was introduced to California to control yellow star thistle is showing the most promise, but yellow star thistle populations remain high.

The problem associated with biological control agents is that they are usually very host specific. From a forester's standpoint, controlling one weed out of a thousand does little to reduce competition. Getting populations of insects established is another concern. In many cases predators reduce populations of beneficial insects to insignificant levels. Some insects only produce one generation per year making establishment difficult (Pitcairn 1999). Using biological control agents is usually out of the forester's control as these programs are usually designed and implemented by the state. There is definitely some potential benefit from biological control, but using insects should be one small part of a larger vegetation management program (Newton & Dost 1984).

Cultural Weed Control Methods

Cultural methods of weed control are indirect management techniques that increase a conifer seedlings ability to out-compete the vegetation. Many types of activities could be considered cultural treatments and more often than not foresters may not even realize they are practicing cultural vegetation management. Regarding this text, we will try and focus on a few of the more relevant concepts.

The Seedling

One of the more obvious cultural treatments a forester can manage is that of producing the conifer seedling itself. Any variable that the forester can manipulate in the nursery to give the conifer seedling a competitive advantage over the vegetation in the field is a cultural treatment. Stock size is the first factor that comes to mind, but different stock sizes behave differently depending on the geography. In wetter high site climates, several authors have shown larger stock sizes for Douglas-fir to increase growth and survival (Ketchum & Rose 2000, Newton et al. 1993). Other authors have shown the stock size effect to be an additive effect when combined with vegetation management and fertilization (South et al. 2001). In drier Mediterranean climates however, Fredrickson (2005) showed that growth differences due to initial stock size were short lived and varied by species. All initial differences in size had disappeared by year 5.

One of the most important seedling variables to manage in the nursery for drier climates, is the shoot to root ratio. Seedlings will compete better with vegetation in the field if they have a balanced shoot to root ratio. Large tops and small root systems cause the seedling to transpire faster than the root system can acquire water for the seedling, resulting in growth loss or death. The nursery manager can manage seedling heights and the shoot to root ratio by regulating photoperiods, thereby tricking the tree into thinking the day length is getting short. This causes the tree to set bud and harden off earlier.

Seedling Nutrition

Seedling nutrition is another critical factor that can give seedlings an initial advantage over the competing vegetation. Timmer (1997) has shown that exponential nutrient loading of seedlings in the nursery can induce a steady state buildup of nutrient reserves in seedlings for out-planting. He has consistently shown greater growth and increased nutrient uptake after out-planting compared to conventionally fertilized seedlings of the same stock size. Powers (1999), has shown the benefit of nutritional amendments in the field to ponderosa pine growth, but only in combination with weed control. If weeds were not controlled, any nutrients added to the site were taken up by the competing vegetation and any potential gains to conifers were lost. Powers also noted that fertilization success in the field also depended on moisture availability and water holding capacity. Others have shown water to be a limiting factor regarding fertilization response in the field (Rose & Ketchum, 2002).

The idea of incorporating slow release fertilizer in with the soil media in the nursery initially showed increased growth responses in the field with ponderosa pine (Fan et al. 2002). However, when operational testing and planting was conducted in California, severe root mortality occurred from salinity build up in the plug media, especially during storage. These problems are exacerbated in hot and dry climates where flushing of the root system from spring rains is sparse. This method of fertilization is not recommended for dry California climates.

Grazing

Grazing is a cultural treatment that has been practiced for centuries. Grazing practices in forestry have been done primarily with ungulates such as cattle, sheep and goats. They are usually effective in reducing the amount of herbaceous and woody brush cover depending on the species present (Sharrow 1992, Fullmer 1986, Krueger & Vavra 1984, Thomas 1983). Reductions in vegetative cover however, are short-term and eventually recover (McDonald & Fiddler 1993). Grazing has also released non-palatable vegetation that has actually increased in percent cover after grazing (Fullmer 1986).

The reduction in vegetative cover does not necessarily mean an increase in conifer growth or survival. Results are mixed in the literature as to the benefits regarding seedling growth and survival. In many cases, no beneficial effect of grazing was seen (Milliman 1999, McDonald & Fiddler 1993), while others have documented increases (Barolome 1989, Krueger & Vavra 1984).

Timing and grazing intensity play a significant part in damage to crop trees. Milliman (1999) reported that browse damage on conifer seedlings was the greatest with the highest intensity of grazing pressure and in June when the early season forage was maturing but before the late season forage had begun to grow. Fullmer (1986), also reported that sheep had browsed 49 percent of ponderosa pine and sugar pine buds at one site when browsing occurred prior to conifer bud set in the summer. Grazing was delayed on a second site until after bud set and browsing conifer buds was reduced to 10 percent.

To manage grazing effectively it is somewhat labor intensive. Fences need to be constructed, maintained and moved as needed. Herds need to be rotated to insure over grazing does not occur. Water can also be an issue if not present on site.

Fire

One of the most common cultural treatments historically used to manage vegetation in forestry is fire. Today with increasing constraints and regulations regarding air quality and smoke management along with general liability concerns, this practice is used much less frequently. Historical uses of fire revolved around reducing post-logging slash and residual vegetation on site. The largest advantage of fire is on steep slopes where heavy equipment cannot be used. The use of fire subsequently reduces difficulty for hand crews when planting, spraying and thinning, thereby, reducing costs (Newton & Dost 1984). Substantial gains in vegetation control have also been shown when burning is used in combination with herbicides (Powell 1992). Burning without the use of herbicides can actually release some fire adapted species such as deerbrush, snowbrush, blue blossum (*Ceanothus thyrsiflorus)* and knobcone pine (*Pinus attenuata*) (Weatherspoon 1987, Newton & Dost 1984).

Fire has been shown to increase conifer survival and growth, especially in combination with herbicides (Taylor et al. (1991). The authors looked at piling, broadcast burning and spraying, burning alone, and all treatments with and without disking. Two years after treatment, the spray plus burning treatment had greater consumption of fuel compared to burning alone, and better vegetation control and seedling growth than either burning alone or the piling treatment.

Under burning is also a valuable tool to clear away under story slash, vegetation and smaller unwanted sub-merchantable conifers. Arno et al. (1996) and Newton & Dost (1984)) noted the importance of thinning in combination with fire, along with utilizing other vegetation management options including herbicides to maximize effectiveness. Burning should not be looked upon for fuels reduction as the sole option. Reducing fuels or creating fuel breaks without maintaining them is a waste of time and money. Vegetation will come back rapidly after fire and needs to be managed to prevent an even greater buildup of fuels (Newton & Dost 1984).

There are several disadvantages to using fire for vegetation management. The liability associated with burning is significant as there is always the risk of escape and associated suppression costs. The importance of developing and following a detailed prescription for any planned fire is essential. The forester must also have the experience and ability to call off a potentially high risk burn when conditions are not right. Cutting, clearing and walking fire-lines on steep slopes can also be dangerous, although, Kauffman (1992) demonstrated that the incidence of worker injury and workers compensation claims during post burning activities such as planting, backpack spraying and thinning was less on units that had been broadcast burned compared to units with heavy slash and brush loads.

Chemical Weed Control

As noted in Forests and Right-of-Way Pest Control (Dreistadt 2013) published by UC Agriculture and Natural Resources, herbicides are the most used pesticides in forests because of their effectiveness in controlling competing vegetation. In the most recent edition of the Pacific Northwest Weed Management Handbook, it was noted that reforestation success depends heavily on weed control and that “In the past 20 years, research has made clear that virtually no other practice will produce as much gain in plantation performance as reducing competing cover, and that careful application of the appropriate chemicals exceeds other methods in safety, cost and habitat protection for most operations." (Kelpas and Landgren 2018). The use of chemicals for weed control in California forestry settings are highly regulated by both the US Environmental Protection Agency and the California Department of Pesticide Regulation. Table 8.1 summarizes the herbicides used in forestry by their active ingredient, type of activity and uses.

Table 8.1 Properties and uses of herbicides registered for forestry use in California. Herbicides noted for directed release means there is no over the top conifer tolerance.

Active Ingredient	Type of Activity	Uses
2,4-D ester	foliar	site prep/directed release
aminopyralid	foliar and soil	site prep/directed release
atrazine	soil	site prep/release
clopyralid	foliar and soil	site prep/release
fluroxypyr	foliar	site prep/directed release
glyphosate	foliar	site prep/release
hexazinone	soil	site prep/release
imazapyr	foliar and soil	site prep
oxyfluorfen	soil	site prep/release
penoxsulam	soil	site prep/release
sulfometuron-methyl	soil	site prep/release - coast only
triclopyr ester	foliar	site prep/directed release

The following sections descried the types of herbicide used in reforestation, resource and applicator protection measures, and logistical issues of application.

Types of Herbicides in Forestry

There are several types of herbicides that are currently used in forestry including growth regulators, ALS inhibitors, photosynthesis inhibitors, protoporhyrinogen oxidase inhibitors (PPO inhibitors) and the newest mode of action, cellulose biosynthase inhibitors. Each controls plants in its own way.

Growth Regulators

Growth regulators used in forestry include triclopyr, 2,4-D, aminopyralid, clopyralid and fluroxypyr. Growth regulators control plants by causing rapid cell wall expansion and collapse. Typical symptoms of growth regulator herbicides include twisting and curling of foliage, stems and roots. Growth regulators come in both ester and amine formulations. Typically it's the oil soluble ester formulations that are used in forestry due to superior weed control and better penetration into leaf surfaces over the water soluble amine formulations. However, use of esters is typically limited to the spring and fall due to volatility issues during the hot summer temperatures. The amine formulations are non-volatile, and fluroxypyr ester is much less volatile than 2,4-D or triclopyr ester.

Growth regulators are primarily used to control woody brush and herbaceous broadleaves (triclopyr, fluroxypyr and 2,4-D). Aminopyralid and clopyralid only have activity on herbaceous broadleaves and some annual grasses, but have both foliar and soil activity. Conifer tolerance with triclopyr and 2,4-D is high when applied as a pre-plant application since there is no soil activity. Neither can be used over the top of conifers in California. Aminopyralid also can not be applied over the top of conifers, but has some conifer tolerance when applied as a pre-plant. Clopyralid has excellent conifer tolerance applied pre or post plant over the top of seedlings. Trees can occasionally be injured from soil uptake as a pre-plant treatment, but if damage occurs at all the trees usually recover in a short amount of time.

Aceto-Lactase-Synthase (ALS) Inhibitors

ALS inhibitors inhibit formation of the enzyme aceto-lactase-synthase in plants that is necessary for the formation of essential aromatic or aliphatic amino acids in plants. These amino acids are only found in plants. These herbicides tend to be highly systemic and travel readily through plant tissues. Examples of ALS inhibitors in forestry include glyphosate, imazapyr and sulfometuron methyl. ALS inhibitors mainly occur as water soluble amines. Ester formulations do not exist and volatility is not an issue.

ALS inhibitors can have foliar and soil activity. Glyphosate is strictly foliar active, imazapyr has both strong foliar and soil activity and sulfometuron methyl is strictly soil active. The three have a mixed range of conifer tolerance as well. Glyphosate may be applied over the top of seedlings that have been established for one year after bud set in the late summer or as a pre-plant application. Applications made over the top of seedlings during the active growing season will cause significant damage or mortality. Release applications with imazapyr in California with a few exceptions are not possible due to very low conifer tolerance both from foliar and soil uptake. Even pre-plant site preparation treatments the year prior to planting may see significant conifer injury from soil uptake. Imazapyr has mainly found a fit in forestry applications in California as a pre-harvest treatment prior to logging that will be discussed further in this text. Sulfometuron methyl may be applied as a pre or post plant application on the Coast over redwood seedlings in California, but in the interior parts of the state with a drier climate, significant root suppression, top stunting, or even mortality occurs in conifers. This is mainly due to the inhibition of root growth and as a result, seedlings are not able to capture available soil moisture.

Photosynthesis Inhibitors

The triazine herbicides which include hexazinone and atrazine control plants by inhibiting the Hill reaction which in turn inhibits photosynthesis. Both hexazinone and atrazine are soil active herbicides which are absorbed by plant roots and require rainfall to activate. Atrazine is primarily a pre-emergent herbicide. Once grass and herbaceous broadleaves grow to over three or four inches tall, efficacy is reduced. Hexazinone is a more powerful herbicide and can be applied as a pre or post emergent herbicide, and has some activity on woody brush, which atrazine does not. Conifer tolerance with atrazine is excellent. Applications can be made pre or post plant to any of the conifers native to california. Hexazinone on the other hand has very good tolerance on ponderosa pine, but moderate to no tolerance on other conifers native to California.

Protoporphyrinogen Oxidase Inhibitors (PPO) Inhibitors

PPO inhibition is a new mode of action to California forestry. PPO inhibitors prevent plants from making the enzyme protoporphyrinogen oxidase which results in the destruction of cell membranes. They kill through lipid peroxidation, which is the process in which free radicals take electrons from the lipids in cell membranes causing the destruction of the membrane. The only PPO inhibitor currently registered in California is a component of Dow Agrosciences' product Cleantraxx. Cleantraxx is a combination of two different active ingredients and two different modes of action. The product contains the active ingredients oxyfluorfen, a PPO inhibitor, and penoxsulam which is an ALS inhibitor. ALS inhibitors have already been explained.

The two active ingredients work well together. Oxyfluorfen and penoxsulam have both soil and foliar activity. Oxyfluorfen controls herbaceous broadleaves and annual grasses only. Penoxsulam is a relatively new active ingredient and the list of plants controlled is still being determined, but it appears to have some activity on herbaceous broad leaved plants and weaker activity on woody brush. It does however, inhibit the germination of several woody brush species from seed. The product works best as a pre-emergent application, but does have some selective knockdown of existing vegetation as a post-emergent application. Conifer tolerance is excellent as a pre or post emergent application on all conifers tested in the northwest.

Cellulose Biosynthase Inhibitors (CBI's)

A recently new mode of action is about to enter into the forestry market as the active ingredient indaziflam. Indaziflam is a cellulose biosynthase inhibitor. It controls plants by inhibiting cellulose synthesis, inhibiting germination and root development. Indaziflam is primarily soil active, but does have minor foliar activity. The best fit with indaziflam is with pre-emergent applications. If vegetation is already existing on site, another product must be added to achieve knock down.

It mainly controls annual grasses and herbaceous broad leaved plants. It does not have any activity on woody brush at all. Conifer tolerance is very high, even on western larch, sugar pine and redwood seedlings which are the most herbicide intolerant conifers in the western United States. Conifer safety is maximized with pre-plant applications. No products with indaziflam are currently registered for forestry use in California.

Differences Between Soil and Foliar Active Herbicides

There are several differences foresters should be aware of regarding the mechanism of uptake that a herbicide has. Soil active products are taken up by the roots and require rain to activate. Foliar active products are taken up through the leaves and in some cases stem tissue. Products with soil activity tend to have longer residual control because they are more persistent and have longer half lives in the environment than foliar active products. Some soil active herbicides like hexazinone tend to be very mobile in the soil whereas, others such as atrazine and oxyfluorfen are much less so. Foliar active herbicides are generally not mobile in the soil. It is possible for a herbicide to have both foliar and soil activity, such as imazapyr which has very strong activity for both.

Soil active herbicides are heavily influenced by soil type, texture and percent organic matter. Those that have a high affinity to adsorb to soil particles are less available for plants to uptake and can negatively affect control. Adsorption to soil particles is measured by the soil adsorption coefficient, or Koc. The higher the Koc, the more that soil adsorbs to soil particles and the less mobile it may be in the environment. This measurement in combination with the solubility (S) of the herbicide can give some indication of the potential mobility of a herbicide in the environment. Highly soluble herbicides are generally more mobile. However, mobility in the environment is heavily influenced by the forest soil. Herbicides in clays or clay loams are generally less mobile than in loamy sands or sands (Dreistadt 2013), as they are in high organic matter soils. Several of the soil active herbicides such as hexazinone strongly adsorb to organic matter hindering plant uptake (Neary, Bush & Douglas 1983). Just because a herbicide has a high Koc or solubility doesn't necessarily mean that it is going to be mobile on any given soil. Results are highly variable in the field. In addition, slope also can have a major influence on mobility.

Non-Synthetic Herbicides

A brief mention will be given to what is referred to as non-synthetic herbicides. These are naturally occurring materials occasionally used for weed control, mostly in organic agricultural programs. They include such compounds as acetic acid (vinegar), citric acid, clove oil, cinnamon oil and corn gluten meal. These compounds are desiccants that accelerate the drying of plant tissue. The herbicidal symptoms they produce are limited to desiccating above ground plant tissue. They do not control the root systems of plants or translocate as true herbicides do.

These material have in some cases controlled very small, freshly germinated herbaceous seedlings. They will not control brush or mature herbaceous vegetation adequately. Plants not killed by these treatments recover rapidly after initial symptoms appear (Chandran 2009, Evans & Bellinder 2009, Moran & Greenberg 2006, Chase et al. 2004, Brevis et al. 2004, Corran et al. 2005, Owen 2002). These types of treatments are completely inadequate for forestry use. It should also be noted that in California, these materials are considered herbicides and need to be registered for use as such by the California Department of Pesticide Regulation. Acetic acid is not on the 25b exempt list of California or the U.S. EPA. However, the other active ingredients such as citric acid, clove and cinnamon oil and corn gluten meal are exempt and do not require registration (unless exceeding concentrations of 8.5% in California). They are considered pesticides in that a licensed pest control business is required to apply them in California but are exempt from reporting and from registration.

Herbicide Behavior in the Environment

Herbicide behavior in the environment is dependent on many things. Degradation rates, solubility, soil sorption capacity, climate, soil type, organic matter, etc, can all play a role in how a herbicide behaves. Potential negative effects of herbicides are easily mitigated. Today's herbicides have very high margins of safety regarding toxicity as well. Knowing how herbicides behave and understanding their toxicology will significantly add to your skill set.

Degradation

Herbicides are broken down in the environment in several ways. The main method of breakdown is microbial (Dreistadt 2013). Microorganisms in the soil rapidly break down most herbicides and in some cases soil arthropods actually utilize them as a food source (Busse, Rapaport & Powers 2000). The second method of breakdown is photolysis, breakdown from light. Not all herbicides photo-degrade. Herbicide breakdown in water is mainly through photolysis and in most cases is fairly rapid (Rhodes 1980).

The length of times it takes a herbicide to break down is denoted by the half-life, the time it takes for 50 percent of the active ingredient to break down in the environment (Dreistadt 2013). Half-lives can range anywhere from a couple of days to six months or more depending on the product, the environment and microbial population. Typically soil active herbicides have the longest half-lives as they are designed to last longer to provide lasting residual control.

Mobility

How mobile herbicides are in forest soils depends on the inherent properties of the herbicide and the environment. Mobility in the soil is influenced by solubility, degradation rate, ability to adsorb to soil particles, soil texture and type, pH, organic matter, slope and precipitation (Beaudry 1990, Neary, Bush &

Douglas 1983). Sandy well drained soils are the most prone to herbicide leaching, and clays are the least. Foliar active products pose little risk from leaching due to very rapid degradation rates. Soil active herbicides are more prone to movement depending on the product. It is important to realize that mobility is strongly influenced by site and that all sites are different. Looking at one or two lab derived indicators of mobility may not give an accurate depiction of what may occur under field conditions.

Toxicity

Herbicides have to pass through over 150 tests to even be considered for federal registration. California has its own testing requirements in addition to the federal ones. Every herbicide's toxicity is carefully evaluated for being a potential harm to human, animal, insect and aquatic life. Toxicity is evaluated for both acute (short-term exposure) and chronic (long-term exposure) hazards. Toxicity information can be found on each product's safety data sheet (SDS). Some of the data collected includes testing for carcinogenicity, teratogenicity, mutagenicity, reproductive effects, endocrine disruption, eye and skin hazards, etc.

Measures of toxicity are usually expressed in milligrams of active ingredient per kilogram of body weight. LC-50 and LD-50 are two frequently used terms that define the toxicity of an active ingredient. LC-50 is the lethal concentration in water required to kill 50 percent of a certain aquatic population of organism, and LD-50 is the lethal concentration required to kill 50 percent of a terrestrial organism (Table 8.2). Another useful term to know is the NOEL. This is the "no observable effect level", defined as the highest concentration of pesticide that did not produce any negative health effects. When used at labeled rates, today's herbicides pose little threat to the environment.

Table 8.2 Relative toxicities of forestry herbicides compared to several common chemicals.

Active Ingredient	LD-50 mg/kg Oral Rat	Source
2,4-D ester	1380	Weedone LV-6 MSDS
aminopyralid	>5000	Milestone MSDS
aspirin	200	aspirin MSDS
atrazine	>2000	Atrazine 4L MSDS
caffeine	192	caffeine MSDS
clopyralid	>5000	Transline MSDS
fluroxypyr	>5000	Vista XRT MSDS
glyphosate	>5000	Accord XRT II MSDS
hexazinone	1310	Velpar DF MSDS
imazapyr	>5000	Polaris AC MSDS
nicotine	50	nicotine MSDS
oxyfluorfen	>5000	GoalTender MSDS
penoxsulam	>5000	Sapphire MSDS
salt	3000	salt MSDS
sulfometuron-methyl	>5000	Oust XP MSDS
triclopyr ester	2966	Forestry Garlon XRT MSDS
vitamin D	42	vitamin D MSDS

Source: MSDS – Material Safety Data Sheets with the official chemical hazard information

Resource Protection Measures for Chemical Methods

There are many resources and sensitive areas that as a land-manager you may wish to remain pesticide free. Protection of these areas is a relatively simple task, and there are a variety of methods that can be used to protect resources, wildlife and property. One of the most valuable documents you should have in your management plan is a list of your company's mitigation measures regarding pesticide applications. Documenting what you do in practice is a necessity, both from a best management practice (BMP) and liability standpoint.

Buffers

Buffers are a designated distance or area of land designed to protect resources, people or property from contact with pesticides. It does not necessarily mean a pesticide free zone. The goal of buffers is to protect an area of concern. A 100 foot buffer, for example, may be used to protect a stream course. The applicator may stop spraying at 100 feet allowing some residue to drift into the buffer zone, but the stream course would still remain pesticide free. There is a major difference between a buffer and a pesticide free zone.

Buffers are the simplest way to protect areas of concern (Figure 8.1).

Figure 8.1 Aerial buffer along a streamcourse. Photo courtesy of John Mateski, Western Helicopter.

In general, aerial buffers tend to be larger than buffers for ground applications, and buffer size can differ between foliar and soil active chemicals. Soil active herbicides generally have larger buffers than foliar active products because soil active herbicides can move in the soil profile but foliar active products cannot. For soil active herbicides, buffer size tends to range between 50 and 150 feet for aerial applications and 50 to 100 feet for ground applications. Foliar active buffers can range from 25 to 100 feet for aerials applications and as close as ten feet or less for ground applications. These distance examples are just to give an idea of what has been used as part of industry BMP's in the past. Buffer size may be more or less depending on the land owner's practices unless it is specified on the product label.

Drift Mitigation

Drift is one of the main areas of concern regarding pesticide applications. There are many ways to mitigate drift and this is where it helps to first have your mitigation measures identified in a written plan. This plan will not only help foresters in the field but can also serve as a living document in legal matters.

Drop size has a major effect on drift. Volume median diameter (VMD) is the drop size where 50 percent of the spray volume is in droplet sizes less than the VMD and 50 percent of the spray volume is in droplet sizes larger than the VMD. As VMD decreases, the percentage of small spray droplets increases. Drop sizes less than 154µm are most prone drift (Yates, Cowden & Akesson 1985, Barry 1984). By minimizing this part of the droplet spectrum, drift can be substantially reduced.

There are many different ways to minimize the number of fine drops. As discussed earlier, nozzle size, nozzle angle, air or ground speed, pressure, boom length and humidity can all affect drop size. Nozzle orifice size is the most obvious way to manipulate drop size. The larger the nozzle orifice, the larger the VMD, and hence fewer small drops prone to drift. It is very important to know what nozzle systems your spray applicators are using and what drop size range they produce. Nozzle angle has a major effect on drop size. Nozzles angled straight back (zero degrees) on an aerial spray boom produced a VMD roughly double that of nozzles angled back at 45 degrees in wind tunnel tests which were used to simulate conditions under aerial applications (Yates, Cowden & Akesson 1985).

Increasing air or ground speed increases the number of fine drops due to increased shear of the spray solution at the nozzle. Increases in pressure will have a similar effect. As pressure is increased, fracturing of the spray solution increases, producing more fine drops. Boom lengths limited to three quarters of the rotor length for helicopter applications will also reduce the number of fine drops by reducing rotor wash at the ends of the spray swath. Making applications in higher humidity ranges that reduce the amount of droplet evaporation during flight, will also reduce the amount of smaller drops (Barry 1984).

One of the most important features on modern helicopter boom systems is the advent of the split boom (Figure 8.2). Split boom applications allow for half the boom to be shut off during application. The result is the part of the swath directly under the body of the helicopter in the center of the boom is free from rotor wash. The result is a spray pattern that falls virtually straight down (Figure 8.3). Buffer strips can be flown with the working half of the boom on the opposite side of the area of concern so that any rotor wash is concentrated on the side of the helicopter furthest away from the protected area.

Figure 8.2 Example of a split boom application. Photo courtesy of John Mateski, Western Helicopter.

Figure 8.3 An example of the precision that is achievable with aerial applications. Photo courtesy of John Mateski, Western Helicopter.

Drift control agents can also be added to the spray solution to reduce drift by increasing the formulation VMD's. Drift control agents reduce the number of fine droplets primarily by increasing the surface tension of the spray solution (Sparks et al. 1988). Spray additives are usually cost effective and cheap to reduce drift, however, conifer tolerance can also be affected (Fredrickson 1994).

Weather Guidelines

To insure safe and effective pesticide applications, it is critical to have a clearly defined set of weather guidelines. Limits on wind speed, temperature, humidity, precipitation and avoidance of inversions should be clearly addressed. Field foresters managing spray projects should also have forms in the field to document the actual conditions that were occurring at the time of application. Portable hand held weather gauges should also be available to accurately document the weather conditions on site. It should also be noted that weather can also be used to mitigate potential concerns. Spraying when light winds are blowing away from areas of concern is one example.

Project Layout and Planning

Too much emphasis can not be placed on the importance of proper project layout and planning to mitigate any potential issues. After the spray plans have been developed for any given area, detailed reconnaissance of the spray areas need to be completed on the ground. Foresters should be looking for any areas of concern such as water courses, springs, wells, property lines, ditches, residences, or other issues that may require protection.

All heliports, water sources and batching areas should be identified and mapped ahead of time. All roads should be driven and checked for hazards prior to the start of the project. Detailed contract maps need to be made that include the spray units along with all water courses, lakes, ponds, heliports, roads, batching areas, property lines, heliports and anything else relevant to the project. The contract needs to have strict guidelines regarding weather and spraying conditions, chemical handling and storage, production rates, safety and record keeping responsibilities. Detailed unit prescriptions regarding pesticide products and rates to be used need to be provided in writing. One of the most important safety mitigation measures is to have a written spill plan and spill kit in case of emergency that clearly defines procedures, personal protective equipment and contact information needed in the event of a spill.

Developing a field packet for both the forester on the ground and the spray applicator insures that everyone has all of the pertinent information they will need to complete the project safely and effectively. Field packets should include a copy of the contract, unit maps, spray recommendations and prescriptions, restricted materials permits and site identification numbers, pesticide labels and material safety data sheets, a copy of the spill plan, any necessary permits and weather and application summary forms. Weather and application records with all pertinent pesticide use data and conditions should be kept daily. Foresters also need to be sure to read and follow all label directions for any pesticide products they are using.

The final and perhaps most important mitigation measure is to physically show the applicator or pilot the units to be sprayed and any areas within that need protection. Do not rely on word of mouth or pictures on a map to convey the message. The liability is too great to not take the time make sure the applicator is fully aware of all sensitive areas and unit boundaries that need to be avoided. Having radio communication with the pilot will also help answer any questions during the application. Portable radios should be supplied to the forester, pilot and batch truck driver to further reduce any potential risks.

On board global positioning systems (GPS) are commonly used to refine targeted aerial application of herbicides so that sensitive areas and areas with desirable vegetation can be avoided. Aerial applicators that use GPS technology should be supplied with geographic information system (GIS) shape files that show the application area, all buffer zones and the heliports that are to be used for the job. Shape files help in the application process as they show on the map where the helicopter has applied material as the application occurs. This allows the pilot and the forester to review the application and correct skips before leaving the application site.

Chemical Site Preparation (Pre-planting) vs. Release Applications (Post-planting)

The type of application and chemical choices foresters will make is largely based on whether the needed treatments are pre-plant (site preparation) or post-plant (release). Once conifers are established on a site, chemical choices and application methods are much more limited due to conifer tolerance issues (Table 8.3).

Table 8.3 Conifer tolerance to forestry herbicides by activity type and season. * conifer tolerance to glyphosate is low until trees have set bud and hardened off in the late summer to fall. ** Hexazinone tolerance varies by conifer species. See Table 8.4

Active Ingredient	Soil Active Conifer Tolerance	Foliar Active Conifer Tolerance	Timing of Highest Tolerance
2,4-D ester	n/a	low	dormant season
aminopyralid	moderate	low	spring/fall
atrazine	high	high	spring/fall
clopyralid	high	high	spring/fall
fluroxypyr	n/a	low/mod	dormant season
glyphosate	n/a	* low/high	post bud set in the fall
hexazinone	** moderate	moderate	spring/fall
imazapyr	low	very low	pre-harvest
oxyfluorfen	high	high	spring/fall
penoxsulam	high	high	spring/fall
sulfometuron-methyl	low/moderate	low/moderate	spring/fall Coast only
triclopyr ester	n/a	low	dormant season

The most effective and efficient vegetation control is usually achieved through good chemical site preparation. The cost of release treatments on a per acre basis is generally much higher than pre planting treatments and the effective control is often lower.

Site Preparation

Chemical site preparation occurs prior to or immediately after planting of any conifer seedlings to assure plantation establishment. These treatments are initially used to control any vegetation that would prevent initial seedling establishment. Site preparation treatments may be applied by air or by ground and may be done prior to, or after logging operations occur. Any vegetation management that is done after the seedlings have been successfully established is considered release.

Pre-Harvest Site Preparation

One of the most effective and efficient methods of forest weed control is pre-harvest site preparation. This method was adapted from mid-rotation release treatments in the southeastern United States and from vegetation management research conducted on bear clover with glyphosate in the northern Sierra Nevada Range in California (Fredrickson 1994, Jackson & Lemon 1986). The process involves treating the most difficult to control woody brush species such as tan oak, golden chinquapin, snowbrush, whitethorn, etc, at least one year prior to logging as an under-story treatment in the stand to be harvested.

There are many benefits from a pre-harvest site preparation system.. The choice of chemical at this stage of the reforestation effort is basically open to any product registered in forestry for site preparation, as conifer tolerance is not an issue. A useful online reference document for the different herbicides described in this chapter is the 'Weed Control Methods Handbook' (Tu, et al. 2001). The primary herbicide used in forestry applications is imazapyr due to its unparalleled efficacy on difficult to control brush. Since imazapyr has conifer tolerance issues from both its foliar and soil activity, it is well suited for pre-harvest application where it will not damage young conifer trees. Prior to the registration of imazapyr in California and the development of pre-harvest applications, no herbicide registered could completely control any of the most difficult woody brush species mentioned above. Treatments with glyphosate, triclopyr, 2,4-D and hexazinone would cause initial brownout, but would not completely kill the root system. Rapid re-sprouting would occur and the need for re-treatments was necessary Fredrickson (2004) showed that units that were pre-treated with imazapyr saved on the average of $200 per acre due to a decrease in release treatment need over the first ten years of plantation establishment compared to non-pre-treated units and units that had been pre-treated with herbicides other than imazapyr.

The registration of imazapyr in California in both the original water soluble (Arsenal AC) and oil soluble (Chopper) formulations provided new tools that could completely control the most difficult to control species. Since imazapyr will also kill conifer seedlings, it can not be sprayed over seedlings. Post planting release treatments are also not possible due to soil uptake of the long lasting imazapyr in most soils in California. Post-logging site preparation applications made the year prior to planting can still cause significant damage from soil uptake in planted seedlings. Even worse damage can occur from foliar contact. Therefore the only practical application timing is pre-harvest.

Pre-harvest applications can be made with other herbicides as well depending on the type of vegetation present. For example, if under-story vegetation is dominated by manzanita or squaw carpet, 2,4-D or fluroxypyr applications would suffice. For heavy deerbrush or snowberry populations, glyphosate could be used. The use of imazapyr broadens the spectrum of control so much and so effectively that it is a rare occurrence for it not to be part of the prescription alone or in combination with other products. Tank mixes with imazapyr, glyphosate and a methylated seed oil greatly broaden the control spectrum and are commonly used in pre-harvest site preparation applications with very good results. When using imazapyr, the oil soluble formulation should be used for evergreen brush in combination with a methylated seed oil. The water soluble formulation does not work well on evergreen brush, but can be used for hack and squirt treatments or for foliar treatment on deciduous brush.

Two predominant application methods can be used with pre-harvest applications. Some method of foliar treatment is typically used to control smaller woody brush. Hack and squirt treatments involve the injection of an active herbicide into a fresh cut and are used to control large woody brush, and sprouting hardwood clumps or hardwood trees. The timing of foliar applications should be during the late spring to late summer when deciduous woody is fully leafed out and the maximum amount of vegetation has germinated on the site. Hack and squirt applications can be done almost year round, with the exception of the spring sap-flow period.

Foliar treatments with pre-harvest applications can be applied as broadcast treatments, directed treatments or a combination of both. Broadcast applications can be applied using the waving wand method with gun-jets, OC nozzles or adjustable tips depending on the size and density of the under-story vegetation. Gun-jet or adjustable tip applications are ideal when the brush is small and the under-story is open and free of obstruction from sub-merchantable conifers or large brush. OC nozzle broadcast applications can occur in denser brush and usually provide better coverage. When there is too much interception from conifers, large brush or the under-story is comprised of the more difficult to control woody brush species, directed spray applications with flat fan nozzles are usually the best choice. Most of the time some sort of hybrid broadcast and directed application occurs where the crew can broadcast apply where the stands are open and the brush is small, and then treat larger brush in a directed fashion as it is encountered. In these circumstances usually OC or flat fan nozzles are appropriate.

When stands have a large component of hardwood trees, sprouts or saplings, hack and squirt treatments are usually required on top of any foliar treatment. Hack and squirt applications in a pre-harvest situation are much more efficient and effective than treating re-sprouting hardwood clumps after logging. Issues with conifer tolerance are also avoided. Depending on the density of hardwoods in the stand, crews can either apply the foliar treatments first and then go back through with the hack and squirt treatment, or if there are not many hardwoods several people on the crew could be designated to hack and squirt while the others do the foliar application.

Figure 8.4 A typical forestry hack and squirt set up.

Figure 8.5 Hacks should be spaced evenly around the circumference of the tree and hacked deep enough to penetrate through the bark to the cambium.

A complicating factor with pre-harvest applications is the logistics surrounding the harvest plan completion, logging schedule and accessibility. In California, the Timber Harvest Plan approval process and all botanical surveys must be completed prior to treatment. Unit boundaries, stream courses, exclusion areas and property lines must all be marked as well. In many cases, new roads have not been built or road reconstruction has not occurred yet. Crews may have to walk or use an ORV to gain access where roads are not available, or in some cases, it may not be possible to pre-treat some units. The treatment schedule needs to consider all of these variables to be as efficient as possible. The treatment schedule may also need to change in the common situation when the logging plan changes. Once a harvest plan is completed and ready for treatment, it is best to treat all of the units in the same year. Trying to just treat units that will be logged the following year, may result in a change of logging plans that leaves the forester with logged units that were untreated.

Although there are many logistical issues to deal with, the benefits of pre-harvest site preparation are many. The long-term reduction in release treatments also means a reduction in overall chemical use while maximizing the amount of vegetation control. A secondary benefit is a reduction in the amount of chemical needed for herbaceous site preparation treatments prior to planting. Prior to the use of pre-harvest treatments, hexazinone was often used for site prep at rates of 2.5 to 3.0 pounds active ingredient per acre as some woody brush could be controlled along with the herbaceous vegetation at those rates. Since the woody brush is already controlled by the pre-harvest treatments, the following hexazinone rates may be significantly reduced as the herbaceous vegetation is the only target and is easier to control. Another unique benefit from the applications is in regard to fall planting. Since all of the vegetation in the unit is already treated, available soil moisture is significantly improved after logging since the units sit fallow through the summer free of trees and vegetation that would otherwise remove available soil moisture. This allows for fall planting to occur earlier and with more water available for planted seedlings (Fredrickson 2002). The need for mechanical site preparation (piling) is often times reduced or removed all together. Treated brush in the under-story has a full season to die and becomes brittle by the time logging operations occur. Often times the disturbance from the heavy logging equipment is enough to crush the existing brush, making the site plantable without any further mechanical site preparation needs.

Post Harvest Site Preparation

Prior to the advent of the pre-harvest site preparation applications, post-harvest treatments were much more common than they are today. The disadvantage of treating brush after harvest operations have occurred is that the majority of plants that survived logging are damaged and do not translocate the herbicide as effectively causing reductions in control (Newton & Knight 1981). The other problem relates to woody brush that has re-sprouted from existing root stocks. In this case, there is rarely enough leaf area after logging to be able to absorb enough chemical to translocate to the existing root system. Usually two to three years of re-growth is required to match the leaf area above ground with the root system below ground to obtain good control. Most often by the time the new seedlings are to be planted, not enough time has elapsed from logging disturbance for brush to recover or achieve the ideal size for treatment.

A different challenge for post-harvest woody brush site preparation occurs after wildfires. Often times woody brush germination is promoted by fire. Seedling populations can be dense and intermingled with surviving damaged brush or woody brush that has re-sprouted from previously existing root systems. In these instances, foresters have no option but to deal with woody brush post-harvest.

If post-harvest site preparation applications must occur, it is usually best to let damaged or re-sprouting brush to recover prior to treatment. Treating brush prior to it achieving adequate leaf area will most likely result in re-sprouting and the need for repeat treatments. The downside of waiting is losing a year or more on the rotation of the new stand. In situations where woody brush germination is primarily from seed, it is most cost effective to treat immediately after germination occurs. Treating seedling woody brush when it is small is magnitudes more cost effective and efficacious than waiting until brush gets larger. With some species on some sites, treatment prior to germination with a soil active herbicide may also be effective.

Whether or not woody brush has been controlled pre or post-harvest, some type of treatment to control herbaceous vegetation prior to planting is also required. The competitive ability of herbaceous vegetation on seedling survival and growth has been well documented (Rose & Ketchum 2002, White, Witherspoon-Joos & Newton 1990, White & Newton 1989, Peterson, Newton & Zedeker 1988, Newton & Preest 1988). Even in the wetter climates of western Oregon Douglas-fir seedlings experienced a 217 percent gain in volume when herbaceous vegetation was controlled over the first three years. Vegetation control on drier sites has been shown to triple volume growth of ponderosa pine (Powers & Reynolds 1999).

Post-harvest site preparation treatments can be applied by either air or hand. Aerial applications are applied broadcast. Suitability of aerial applications on brush is dependent on the type and size of brush. Usually evergreen species of woody brush are controlled more effectively with hand applications. Imazapyr treatments by air are highly effective on evergreen brush, but they should not be applied the year prior to planting due to potential conifer damage from soil uptake of Imazapyr. Treatments applied earlier than that should have no residual effect on conifers. Site preparation application by air over species such as deer brush or snow berry with glyphosate can be highly effective as can 2,4-D over smaller manzanita. When dealing with seedling woody brush, the smaller the plants, the more efficacious the treatment will be. Larger or re-sprouting brush from root stocks would probably be more suited to hand treatments.

Site preparation treatments on woody brush by hand can be applied by either broadcast or directed methods, depending on the size and species of brush. Similar to the aerial applications, broadcast treatments for brush by hand should focus on the easier to control species such as deer brush, snow berry or manzanita. The more difficult to control evergreen brush or hardwood sprout clumps should most likely have a directed hand spray treatment unless imazapyr is used more than one year prior to planting. Hardwood sprout clumps should also be treated with a directed hand spray or basal treatment depending on the species.

Herbaceous treatments either by air or by hand should be applied with a broadcast method. Soil active herbicides are used for broadcast herbaceous treatments almost exclusively. Occasionally glyphosate can be used in a post-emergent setting, but this is not the preferred treatment as it does not provide any soil residual. Soil active herbicides are dependent on rain to activate and the timing of application is critical to maximize the chances of getting the correct amount. Too much or too little rain can severely impact efficacy. Usually between three and twenty inches of rain is ideal for soil active products. The timing of application depends on seasonal rainfall total, elevation, snow level, access and soil type. Low elevation units that receive a high seasonal rainfall total should be applied in the spring at a time when the forester thinks the necessary amount of rain can be achieved. High elevation units that receive mostly snow should be applied in the fall to assure adequate moisture is received. Access to these sites in the spring may be impossible due to snow until after the spring rains have ceased. Areas on the east side of the Cascade or Sierra Nevada Range should also be applied in the fall as the majority of these sites are in high elevation, low rainfall sites that may only receive 15 or 20 inches of precipitation annually. A general rule of thumb that may be utilized in most areas is units under 4000 feet elevation should be treated with residual herbicides in the spring and those over 4000 feet elevation should be treated in the fall.

When using soil active herbicides for pre-plant site preparation, it is extremely important to know what species of conifers are going to be planted on the treated site and what their tolerance is to the chemicals being used (Table 8.4). While hexazinone provides the best overall control of any of the soil active herbicides, Douglas-fir (*Pseudotsuga menziesii*), white fir (*abies concolor*), sugar pine (*Pinus lambertiana*), incense cedar (*Calocedrus decurrens*) and western larch (*Larix occidentalis*) are to some degree intolerant to hexazinone. Some tolerance issues can be mitigated through rate reductions for species such as Douglas-fir and white fir, while other species have almost no tolerance for it. The use of sulfometuron methyl in the interior parts of California and southwest Oregon can cause root growth inhibition in almost all conifer species. The only two soil active herbicides registered for use in California that have virtually no tolerance issues are atrazine and oxyfluorfen plus penoxsulam.

Table 8.4 Tolerance of commercial conifers for the main soil active herbicides used in site preparation. * Douglas-fir tolerance to sulfometuron-methyl is low in the interior parts of California and moderate on the Coast.

Conifer Species	Hexazinone	Atrazine	Sulfometuron Methyl	Oxyfluorfen + Penoxsulam
ponderosa pine	high	high	low	high
Douglas-fir	moderate	high	* low/moderate	high
white fir	low	high	low	high
incense cedar	low	high	low	high
sugar pine	very low	high	low	high
red fir	moderate	high	low	high
redwood	very low	high	moderate	high

Overall, site preparation applications have the most flexibility of any chemical treatments due to the lack of conifer seedlings and tolerance issues. The best money a forester can spend is on good site preparation. Controlling competing vegetation correctly from the start will save numerous applications, reduce overall herbicide use, increase survival and growth, reduce applicator exposure, and save thousands of dollars for the land owner. Remember this quote from Professor Emeritus Michael Newton of Oregon State University. "If you have a large release program, you're probably screwing up."

Release Applications

Weed control treatments after seedlings have been successfully established are referred to as release treatments. The trees are being released from the competitive effects of vegetation. These treatments can be the most expensive investment of any reforestation effort. Chemical choices are limited due to conifer tolerance issues and many of the treatments must be applied by hand (Table 8.4). Often times certain woody brush species cannot be effectively controlled because the ideal herbicides are not available for release.

Release treatments are most beneficial early in a plantations life. Delaying release treatments increases costs as well as diminishes the growth response of crop trees (Fiddler & McDonald 1999, Newton & Knight 1981). Significant increases in survival, stem diameter, height and volume have been well documented for herbicide release treatments in California (Fiddler, McDonald & Mori 2000, McDonald & Fiddler 1999, McDonald & Everest 1996). While some type of release treatment during plantation establishment is usually required, a truly successful reforestation program will minimize release needs as much as possible through good site preparation.

Chemical release has several advantages over other methods of release such as mechanical or manual methods. Effectiveness and cost are the major advantages, but chemical release treatments also have the least impact on the forest soil in terms of generating erosion or new infestations of weed species that require disturbance to germinate (Newton & Knight 1981).

Aerial Release Applications

Aerial release applications are the most cost effective method of release, but they are also the most limited. They are limited due to conifer tolerance issues with over the top applications. Soil active herbicides including atrazine and oxyfluorfen plus penoxsulam can be applied over the top of all conifers, but options with hexazinone and sulfometuron methyl are more limited. Surfactants are not usually needed with soil active products but should be avoided in most cases because they can reduce conifer tolerance. The exceptions to this are with atrazine or oxyfluorfen plus penoxsulam.

Not all herbicides are registered or have conifer tolerance for applications over the top of planted conifers. Two of the more common ones that do are clopyralid and glyphosate. With glyphosate applications, timing is the most critical factor to avoid conifer injury. Broadcast applications must be applied in the late summer or early fall after conifer seedlings have set bud and hardened off for the year. Application made earlier than that will result in conifer injury or death. Applications over the top of newly planted conifers with glyphosate products is not advisable and restricted on most labels.

The type of glyphosate product applied is also critical. Most formulations of glyphosate do not have an aerial release label approved for over the top applications. Rodeo is a non-surfactant formulation of glyphosate that is labeled for aerial release treatments. Since no surfactant is formulated into the product, one must be added to achieve adequate efficacy on the vegetation. Additional care must be taken in choosing an adjuvant. Most surfactants or adjuvants will increase conifer injury when added to a glyphosate formulation. Historically, only tallow-amine surfactants have had enough conifer tolerance to be safely added or formulated into glyphosate formulations. Currently Penetron is the only tallow-amine surfactant labeled in California for aerial release treatments with glyphosate. Other types of adjuvants such as drift control additives, acidifiers or oils can also increase the risk of conifer injury. With the large number of generic formulations of glyphosate, care must be taken to insure the product chosen is labeled for aerial release.

The species of vegetation that may be controlled with aerial glyphosate release applications is also limited to those species previously mentioned. Herbaceous vegetation control with soil active products does not differ from what was discussed for aerial site preparation applications.

Hand Release Applications

When aerial applications cannot be used or foliar herbicide tolerance to conifers is an issue, treatments must be applied by hand. All hand application methods are available for release needs. Similar to aerial applications, broadcast hand treatments are limited to those herbicides which have conifer tolerance when applied over the top such as glyphosate in the fall or the soil active herbicides as previously mentioned.

If more difficult species are present, another application method must be utilized. Where species such as tan oak, snowbrush, golden chinquapin or live oak (*Quercus chrysolepis*) are present, foresters are faced with tougher challenges. Where these species would have been easily controlled with imazapyr in a pre-harvest application, conifer tolerance issues prevent it from being used in most areas for release. In this case, the forester must determine the most efficacious and cost effective method to use. Choosing the type of herbicide is to a large degree dictated by the type of vegetation that is in need of control. Identification of a complex series of weed pests that are present in the application area is important. For example, a unit the has predominantly manzanita, snowbrush and chinquapin, the best choice of a herbicide for a release treatment might be 2,4-D plus triclopyr in the fall. If that vegetative complex also included cherry and deerbrush, it may be more prudent to apply glyphosate with a methylated seed oil during the growing season. Application timing and chemical choice are in some instances different in separate regions of California. It is best to consult local foresters that are licensed pest control advisors in any given area.

For these difficult to control evergreen species, in some areas directed spray applications of growth regulator herbicides or a high concentration glyphosate treatment may be the best option, in other areas basal bark or spot-gun applications may be best.

When glyphosate became generic the price dropped significantly. Most glyphosate products were always labeled for high concentration directed spray applications in the five to ten percent solution range, but prior to going off patent it was cost prohibitive for anything but scattered black oak treatments. The cost savings of generic products allowed foresters to treat larger areas and more species with higher rates of glyphosate, usually in combination with a methylated seed oil. Glyphosate is one of the safest and shortest lasting herbicides in the environment. It is also non-mobile and poses little risk to fish or wildlife when applied according to the label. Therefore, these applications had many attracting qualities. Timing is critical with glyphosate applications. Treatments from late spring to mid-summer are most effective on evergreens such as snowbrush, whitethorn and manzanita. Treatments later in the season have proven to be less effective in September and ineffective after the onset of cold weather. Tan oak and golden chinquapin are only partially controlled with glyphosate. These glyphosate treatments can reduce the amount of re-sprouting that occurs with snowbrush and whitethorn compared to treatment with growth regulators. Early season glyphosate treatments also allow foresters to control any existing herbaceous vegetation with lower volumes and glyphosate rates.

The high concentration glyphosate treatments can provide a very broad spectrum of control, however there is a tradeoff. The amount of solution volume required to control the more difficult evergreen species can increase labor costs significantly. These are not the most efficient applications from a labor stand point. Applicators also need to be careful not to exceed maximum label rates. The other drawback is that the timing for the best efficacy occurs when the tree seedlings are actively growing and the most intolerant of the chemical. Seedling protection is required when these applications occur. Some type of shield plus a spray bottle filled with water to wash trees accidentally sprayed should be carried.

High concentration glyphosate treatments have a very good fit for re-sprouting black oak clumps provided they are not too large. Ten percent solutions of glyphosate will adequately control black oak clumps and are applied at extremely low volumes and highly cost effective. Clumps can usually be treated safely to a height of about five or six feet tall. Once they grow larger than that too much over-spray occurs that may potentially injure conifer seedlings. These treatments are not as effective on other deciduous hardwoods such as dogwood or big leaf maple. Lower concentration glyphosate applications should be used if the target vegetation is mainly comprised of herbaceous vegetation and deciduous woody brush other than hardwood sprouts. Seedling protection is still required.

Growth regulator herbicides such as triclopyr, 2,4-D and fluroxypyr can also be used for directed spray applications when there is evergreen woody brush present. Foliar applications with growth regulator products on deciduous brush are not recommended due to high rates of re-sprouting following application. Growth regulators provide excellent burn down of most all vegetation and completely control some woody evergreens such as manzanita and squaw carpet. Results on most woody evergreen species result in at least some re-sprouting. Repeat treatments may be necessary on species such as snowbrush, chinquapin, tan oak and whitethorn. Seedlings are also highly sensitive to triclopyr and 2,4-D, and slightly less so with fluroxypyr but seedling protection is required in all cases. Volatilization is also a concern and applying in temperatures over 75 degrees should not occur.

Where there is a mix of deciduous and evergreen woody brush, growth regulator herbicides should never be mixed with systemic products such as glyphosate or imazapyr. The growth regulators do so much damage to the translocating tissue in the deciduous plants that neither glyphosate or imazapyr can get where it needs to go to work in the plant. Deciduous plants will re-sprout much like when treated with growth regulators alone.

Spot-gun treatments with liquid hexazinone can provide a highly effective and efficient treatment if the brush is not heavy. Snowbrush is usually the primary target and is controlled very effectively. Spot-gun can also be used on other brush such as deer brush, whitethorn and manzanita. If cover is very heavy, directed applications with glyphosate or growth regulators may have to be used.

Basal bark or hack and squirt applications may be utilized on more difficult to control hardwood sprouts such as big leaf maple, dogwood or live oak. Their use depends on the efficacy in the region and the conifer tolerance of the species planted on site. In general, hack and squirt should not be used with imazapyr where ponderosa pine is planted. Damage may not appear immediately, but imazapyr flashback can show up several years after the application. Basal bark or high concentration glyphosate applications may be more appropriate. Without the use of imazapyr, controlling hardwood sprouts other than black oak is difficult.

Cut stump applications for release are rarely used in forestry due to cost, but may occasionally have a fit if the amount of saw work is light.

It may appear that achieving adequate control with release applications is difficult. It is possible, but definitely more difficult than controlling vegetation as a site preparation application. The presence of conifer seedlings severely limits management options compared to site preparation. It is not hard to see that by controlling the more difficult evergreen species effectively during site preparation, cost, chemical used, worker exposure and vegetative cover can all be reduced while enhancing conifer survival and growth.

Project Level Considerations Before Choosing a Chemical Control Method

Treatment Objectives

The first thing you need to determine is the species of vegetation you are trying to control. There is no magic bullet. In defining your objectives for the treatment, you need to evaluate the vegetation complex and determine which species are the greatest problems. The most efficacious method can then be determined. Many species are not controllable with aerial applications, some are limited to certain types of hand treatments, and for some, there may not be a suitable control technique at all. Your objective is to determine what the main treatment need is and to do the very best that you can.

Cost

Your budget will dictate much of what you can and can't do as far as application methods go. Aerial applications are the least cost option due to the amount of area that can be covered in a very short amount of time. Aerial forestry applications are mainly limited to helicopters due to the topography, but where large tracts of flat clean ground exist, fixed wing aircraft applications may be possible. Ground treatments with a tractor or other ground equipment are fairly cost effective, but also very limited in use due to topography, slash loads and stumps. In increasing order of cost, application methods range from fixed wing aircraft to helicopter, then to tractor or other type of ground machine, with hand applications usually being the most expensive.

Much of the cost of hand applications depends on the type of treatment that is being done. Directed (or spot) treatments where individual plants are specifically being treated are the most expensive. Broadcast applications by hand are very efficient and can in certain types of treatments rival helicopter costs. Familiarity with all the different types of application methods and their availability is critical. When conducting sprays by hand, having a crew that can apply them efficiently and effectively will often reduce application costs more than anything else you could do.

Effectiveness

The different application methods will have varying results compared to each other mainly due to differences in coverage. This is mainly true for foliar applications where coverage on leaf surfaces is critical. Coverage from aerial applications is not as consistent, or as thorough as coverage from hand applications. When foliar contact herbicides like glyphosate, imazapyr, triclopyr, fluroxypyr or 2,4-D are used, efficacy is usually best with hand treatments compared to aerial applications depending on the type of vegetation treated.

The type and size of vegetation will also determine how effective an application technique will be. As woody brush gets larger, it gets more difficult to control by aerial methods. Deerbrush (*Ceanothus integerrimus*) is fairly easy to control by air with glyphosate when it is small. If large deerbrush is treated by air, it may only top-kill plants and result in subsequent resprouting. Evergreen brush such as tan oak (*Lithocarpus densiflorus*), golden chinquapin (*Chrysolepis chrysophylla*) and snowbrush (*Ceanothus velutinus*) are very difficult to control with aerial methods depending on the type of herbicide used.

Coverage for soil active herbicides like hexazinone, sulfometuron, oxyfluorfen, penoxsulam and atrazine is less critical than foliar applied herbicides. Soil active products tend to spread in soil when in contact with moisture, and are much more forgiving if coverage is not complete. Application method makes much less of a difference with soil active products provided that the application is done correctly. The greatest risk with hand applications and soil active products are skips and proper calibration.

Conifer Tolerance

Herbicide choice and conifer tolerance will also dictate what application methods you can and can't use. Broadcast applications over the top of established seedlings by aerial or ground methods are not possible with herbicides that provide little conifer safety. In this case, directed hand treatments may be the only option. Time of season may also dictate when over the top applications can occur with certain herbicides like glyphosate. Conifers are tolerant to over the top applications of glyphosate in the fall, after buds have hardened off. If treatments occur prior to that, conifer damage or mortality will occur.

Scope of Project

What type of application method you use may depend on the size of project and availability of local applicators. Aerial applications are well suited for large projects. Helicopter applications can usually treat up to 300 or more acres per day. Hand crews trained to do efficient broadcast applications can treat between 100 and 150 acres per day. If directed hand spraying is required, production rates may drop down between 30 and 60 acres per day depending on the size and density of brush, access, etc. Scheduling out your project to make sure you complete your objectives is critical. You should have a production plan and make sure contractors are completing the required amount of acres per day, weather permitting.

Logistics

Logistical concerns may also influence the type of application method you use. Access is critical for ground spraying operations. Without good access, costs can rapidly get out of control. In this case, aerial applications may be more appropriate. To make aerial applications efficient, heliports, road access, water sources, staging and storage areas all must be available and in good condition for a successful program.

Liability Issues

With any spraying operation, there are potential liability concerns. The land manager's responsibility is to anticipate and mitigate these concerns and therefore minimize liability to the landowner and risks to the environment. The risk of liability can also dictate what type of application method you choose. If you are spraying close to adjacent dwellings, a critical analysis of application method should be conducted, and aerial applications should probably not be the method of choice. Ground applications are a good choice when spraying around areas with water, wells, domestic ditches, property lines or other areas where herbicide buffers need to be precisely applied. Many times a combination of hand and aerial treatments can be used, where hand treatments are applied around sensitive areas and aerial methods are used to treat the remaining areas. Aerial applications can be made very precisely, but alleviating concerns utilizing alternative methods can go a long way in gaining trust and ensuring future projects progress according to plan.

Site Specific Issues with Chemical Vegetation Control

Variables That May Affect Chemical Applications

There are many things to consider that may affect your chemical application, any one of which may negatively affect the outcome if not considered and planned for. Probably the most important physical influence on spray operations is the weather. Weather can influence everything from efficacy to drift. As a land manager, it is imperative to know the conditions to avoid to achieve a safe and successful application.

Temperature can influence applications in several ways. As temperatures increase, smaller spray particles are suspended in the air for longer periods of time and can drift away from the application site (Barry 1984). Generally, as temperatures increase, the risk of offsite movement increases. Herbicides that are volatile ester formulations are subject to increased volatilization rates as temperature increases and humidity decreases. Volatilization occurs when temperatures rise, turning the ester herbicide formulation from a liquid into a gas phase (Gratkowski & Stewart 1973). The gas phase of the herbicide maintains its phytotoxic properties and can move off the application site causing damage to desirable vegetation. Volatilization can be exacerbated on open rocky sites or sites with light colored soils with little ground cover. Application of these types of chemical during extended periods of hot, dry weather may be infeasible. The herbicide labels of volatile esters often restrict application if the temperature is in excess of 75 degrees or is expected to exceed 75 degrees immediately after application. Most herbicide formulations now are either low volatile esters or amines. Low volatile esters have the potential to volatilize and cause off-site movement of the herbicide under adverse conditions, but are less likely to do so than regular ester formulations. Volatilization with amine formulations of herbicides are negligible and are more suitable for use in areas or under conditions where volatilization would cause an adverse effect. New choline formulations of herbicides almost do not volatilize at all.

Humidity and wind also play an important role in spray applications. Spray drift increases as humidity decreases and winds increase (Gratkowski & Stewart 1973), and if spray particles move offsite, both the efficacy on onsite target vegetation and the potential damage to offsite vegetation can be greatly affected. Generally, winds less than five miles per hour are acceptable for aerial applications and winds should be less than ten miles per hour for ground applications.

Temperature inversions are frequently referred to on pesticide labels as a weather condition that prohibits herbicide application. In a temperature inversion, cold air is trapped under a layer of warmer air. This phenomenon typically occurs in valleys or basins during periods of calm winds. If an application is made during a temperature inversion, spray particles can get trapped in the inversion layer and move great distances horizontally. Spraying under these conditions should be avoided due to the high potential for off-site movement (Dreistadt 2013).

Rainfall can have an effect on spray applications. For foliar active products, rainfall too soon after application can wash the active ingredient off of plant surfaces before penetration occurs, thereby reducing efficacy. Several hours are usually required for adequate drying of herbicide residues on plant tissue, but this time can be reduced with the addition of a spray adjuvant that increases penetration into leaf surfaces.

Soil active herbicides require rain to activate, and in this case, rainfall is a necessary part of the equation for successful applications. Too much or too little rain can have a major effect on efficacy and possibly conifer tolerance.

Timing

One of the most overlooked factors that contribute to successful herbicide applications is timing. Target vegetation is more or less susceptible depending on the time of year, and different types of herbicides have different application windows as well. Woody deciduous brush is usually most susceptible in late summer to early fall with systemic herbicides (Cole & Newton 1989), whereas, woody evergreen brush is usually more susceptible in the late spring to early summer with either systemic or growth regulator products (Jackson & Lemon 1986, Paley & Radosevich 1984). Herbaceous vegetation has a small treatment window in the early spring for foliar active products, before senescence occurs in the early summer.

The timing window for soil active herbicides depends on soil moisture availability, as these products require rainfall to activate. The timing usually depends on elevation, geography and annual precipitation patterns (White, Witherspoon-Joos & Newton 1990). Ideally, soil active products in lower elevations are usually applied in the spring to avoid the bulk of the winter precipitation, whereas high elevation sites where snowfall is the predominant precipitation are usually treated in the fall. It is essential to understand how much precipitation is too much or too little and base the application timing on the period you think will come closest to receiving the proper amount.

For foliar herbicide applications that are applied over the top of existing conifers as a broadcast application, the proper timing depends on when the trees are hardened off and tolerant to the herbicide. Conifer tolerance to foliar herbicides is usually greatest in the late summer or fall after buds have hardened off (Radosevich et al. 1980). The least tolerant period is when trees are actively growing. Since soil active herbicides are usually applied in the late fall or early spring when trees are still dormant, most soil active products can be applied over the top of planted seedlings without foliar injury.

Soil Type

Soil type plays a major role in how soil active herbicides work. The active ingredient in many herbicides adsorbs to organic matter in forest soils. The higher the percent organic matter, the more active ingredient is tied up in the soil and unavailable for plant uptake. Soils with high organic matter contents may require higher rates of herbicide, or the organic content may be so high that soil active herbicides may not work at all (Johnson 1987).

Soil texture also plays an important role with soil active herbicides. Soil active herbicides are more mobile in porous well drained soils with higher sand content and less mobile in soils with higher clay contents (Johnson 1987). Soils that are well drained with low organic matter contents also carry a higher risk of conifer damage due to the herbicide being more available for plant uptake. Risk of leaching also increases as organic matter decreases and porosity increases. Land managers need to be particularly concerned on steep slopes with well drained soils when there are sensitive areas that are at risk from leaching.

Topography

Topography can also play a role in how herbicides behave and can affect the quality of application. Steep slopes are more prone to leaching, especially in well drained soils or rocky sites. They are also more hazardous for the applicator, with both ground and aerial applications. Steep slopes usually require slightly larger buffers to assure contamination of watercourses does not occur. Even aspect can play a role regarding efficacy. Under drought stress conditions, hot south facing slopes can stress plants to the point that herbicide uptake is negatively affected.

Herbicide Formulation

It is important to understand how the herbicide formulation itself can affect efficacy. The herbicides used in forest applications are either liquid, granular or dry flowable formulations soluble in water. Liquid formulations are either formulated as amines or esters. Esters are soluble in oil, amines are only soluble in water. Esters can penetrate thick waxy cuticle layers on leaf surfaces easier than amine formulations, and this is why esters tend to be more efficacious on difficult to control woody evergreen brush than amine formulations. There is a drawback however. Ester formulations have a higher vapor pressure than amines and will volatilize at higher temperatures. Amines may be used at higher temperatures, but efficacy may suffer. Amines have shown excellent efficacy on deciduous woody brush or herbaceous broadleaved plants and grasses. Amine efficacy on woody evergreen brush has improved since the advent of the methylated and ethylated seed oil adjuvants.

The dry formulations present somewhat of a different challenge. With granular products that are spread over the landscapes surface and rely on rainfall to activate, the only real concern is making sure the distribution of material through the application system is adequate for even coverage. When dry products such as dry flowables, wetable powders, etc are used, constant agitation during mixing and application is critical to achieve consistent rates when applied. Today's dry flowable formulations go into solution well compared to older formulations.

Spray Application Technology

Understanding the interactions between application variables such as drop size, volume, rate and adjuvant can be very complicated and varies greatly by active ingredient and species to be controlled. However, understanding the basic principles can greatly improve both the efficiency and efficacy of applications.

Drop Size

Drop size can influence several different aspects of spray applications. For foliar applications, the smaller the drop size the greater the surface area of spray solution available to contact plant surfaces. This does not necessarily mean an increase in efficacy, just more efficient coverage of plant surfaces (Fredrickson & Newton 1998). The tradeoff is smaller drops tend to drift. Large drops reduce drift significantly but coverage is negatively affected (Akesson, Yates & Wilce 1970). For soil active herbicides, drop size does not affect efficacy, so it would make sense to use larger drop sizes to reduce risk of offsite movement.

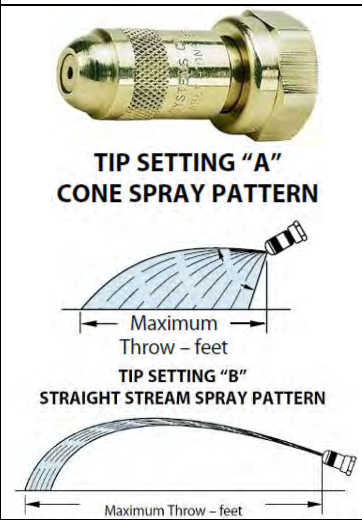
Several physical factors can influence drop size. Choice of nozzle size is the most obvious one. It is extremely important to know exactly what nozzles spray applicators are using for either ground or aerial applications. Your choice of nozzle will vary depending on the type of application you are doing. Certain applications may require smaller or larger droplets depending on the objective. The greatest liability with small drops is with aerial applications, and it is absolutely imperative that land managers are doing all they can to minimize the risk of offsite movement. Small drops should be avoided with aerial applications unless the risk of offsite movement is minimal.

It is important to be aware of other factors that can reduce drop size. Pressure at the nozzle can affect drop size - as pressure at the nozzle increases, drop size decreases. Air or ground speed also affects drop size through shear at the nozzle. The faster the application equipment is moving, the smaller the drop size. Nozzle angle can influence drop size with aerial applications. Drop size is decreased as the nozzle angle increases from horizontal in the direction of travel. The greatest drop size is achieved with nozzles angled straight back, reducing nozzle shear (Yates, Cowden & Akesson 1985). For helicopter applications, boom length is a critical factor controlling drop size and spray deposition patterns. The shorter the boom relative to rotor length, the less rotor wash and liquid shear at the nozzle. As boom length increases, a significant vortex occurs from downward airflow created from the rotors, decreasing drop size.

Nozzle Characteristics

Since nozzle selection has the largest influence on drop size and drift, it is important to understand some basic nozzle characteristics (Table 8.5). Nozzle type will differ depending on the type of application. Selection of nozzles for aerial applications can be quite different from those used in ground treatments, although there can be some overlap depending on the application method.

Table 8.5 Common nozzle types used in forestry applications and their spray patterns.

Nozzle	Type	Pattern	Uses
11004	tapered flat fan		directed hand spraying, broadcast applications on a fixed boom.
8004	even flat fan		band applications
OC-12	off center		waving wand hand broadcast applications, roadside boom
D-6	disk		aerial broadcast, hand broadcast with a gun-jet, spot gun applications with a meter-jet
5500	adjustable tip		basal treatments, hardwood clump sprouts, waving wand hand broadcast applications

The most common nozzle used for hand directed spray treatments is the flat fan nozzle. Flat fan nozzles come in a wide range of sizes that produce anywhere from very small to very large drops. Flat fan nozzles are designated by a series of numbers. The first two or three numbers are the angle of the liquid that is emitted from the nozzle orifice. The last two numbers are the gallons per minute put out through the nozzle at a set pressure, usually 40 pounds per square inch (psi). An 8003 nozzle for example has a liquid spray angle of 80 degrees and each nozzle puts out a spray volume of 0.3 gallons per minute at 40 psi. The larger the last two numbers are, the greater the drop size. Flat fan nozzles are also made in two different spray patterns, tapered or even. Even flat fans maintain the same spray width from the center to the ends of the spray pattern. Tapered nozzles are widest in the center and get narrower at the ends of the spray patter to allow for overlap of the spray solution. Even flat fan nozzles are primarily used for banded applications in agriculture, whereas tapered nozzles are the main ones used in forestry. The specifications may vary somewhat depending on the nozzle manufacturer.

One of the most popular nozzles used for broadcast applications by ground in forestry is the off center (OC) nozzle. These nozzles produce a much different spray pattern than flat fan nozzles. The spray solution is emitted from one end of the nozzle and thrown out away from the applicator in an arcing pattern. This nozzle produces excellent coverage when the nozzle is attached to a hand held spray wand and waved side to side for broadcast applications. The nozzles are designated with two letters followed by a number. A popular off center nozzle used in forestry is an OC-12. The OC stands for "off center" and the number designates the gallons per minute emitted from one nozzle at 40 psi. In this case the 12 stands for 1.2 gallons per minute, whereas and OC-06 would emit 0.6 gallons per minute. Similar to flat fan nozzles, the larger the number, the larger the drop size.

Aerial applications in forestry primarily use some type of disk or disk core nozzle that relies on air speed and nozzle angle as well as orifice size to manipulate the spray pattern and drop size produced. Disk nozzles produce a spray pattern in the form of a stream, and when a disk core is added to the nozzle, the spray pattern produced is a cone. The cone pattern produced by disk core nozzles can either be hollow in the center or completely covered. This is the difference between a hollow or full cone nozzle. Many aerial applicators choose to apply pesticides without a core and just use the disk orifice to produce a stream from the nozzle. In this case, the applicator relies on air speed and nozzle angle to shear the stream and produce a desirable spray pattern. This significantly reduces drift by creating larger drop sizes, but coverage may be affected as well.

The most popular aerial nozzles for helicopter applications currently used are probably the D series disk nozzles. With these nozzles, the D stands for disk nozzle and the number refers to the nozzle orifice size. In this case, the number does not specifically correspond to a certain volume per minute, but to an increase in orifice diameter. A D-8 disk nozzle puts out significantly more volume and a larger drop size than a D-4 nozzle. It is important to realize that the drop size produced from the nozzle on the ground while not moving is going to be much greater than when attached to a boom at a certain angle and traveling at a relatively fast air speed. As air speed increases and the mounted nozzle angle from horizontal increases, drop size decreases. D Series nozzles are also the one nozzle that is used for both aerial and hand applications. They are the main nozzle chosen for broadcast hand applications when using the gun-jet application method.

This is just a brief explanation of how some of the more commonly used nozzles work. There are many nozzles to choose from and the designations may vary slightly, but they all work under the same general principals. The are also many specialty nozzles that may have some limited use in forestry. The importance here is to realize that the choice of nozzle can have a significant effect on the success or failure of an application. The volume, rate, efficacy, deposition and cost per acre can all be affected by nozzle choice. If a hand crew is applying herbicides and the crew members do not all have the same nozzles, application rates between applicators can vary dramatically. The same can be said for a helicopter boom that is not fitted with all the same nozzles. It is imperative to pay attention to these application parameters.

Application Volume

Changing the application volume per acre can affect several spray parameters including cost. In general, volume per acre has little effect on efficacy with a few exceptions. Glyphosate has repeatedly shown to be more effective at low volumes per acre (Cranmer & Lindscott 1990, Buhler & Burnside 1987, Ambach & Ashford 1982). More than anything, volume per acre affects coverage. Coverage increases as volume per acre increases. A fairly large portion of spray volume is lost however due to large drops splashing off of leaf surfaces (Young, Hart & Hall 1987). Volume per acre can best be managed by nozzle size and travel speed.

The main drawback of using high spray volumes is cost. As spray volume increases, the time required to spray a given area increases as does the cost per acre. This is most dramatic with hand applications. Labor costs for hand applications can easily double just by doubling the spray volume. Often times, foresters mistakenly attribute increased efficacy to increases in the volume of herbicide solution applied. In reality, this is actually due to an increase in herbicide rate from higher volumes applied. Efficiency of applications can be significantly improved with higher rates and lower spray volumes (Fredrickson 1994).

Rate

The most important variable affecting efficacy is rate (Fredrickson & Newton 1998, Fredrickson 1994). Many times an increase in volume is mistakenly given credit for increased efficacy, when it was actually the inherent rate increase with increasing volume that was responsible. The challenge for foresters is to use the least rate possible to achieve maximum efficacy, hence increasing efficiency. Most herbicides are expensive and making applications as efficient as possible can easily justify the effort.

Adjuvants

Adjuvants are any type of additive to the spray mixture that changes the physical properties of the spray solution. Surfactants, spreaders, stickers, buffering agents, etc are all adjuvants. The main adjuvant type discussed here will be surfactants. Water has a high surface tension that causes droplets to bead up on leaf surfaces. Surfactants reduce surface tension causing spray droplets to spread over leaf surfaces maximizing coverage (Hess & Faulk 1990). Surfactants also aid in penetration of waxy leaf cuticles, increasing the amount of active ingredient absorbed into the plant (Geyer & Schnerr 1988). Rainfastness can be improved with the use of adjuvants by speeding up absorption rates into plant tissues (Sundaram 1990(a), Sundaram 1990(b), Stevens & Zabkiewicz 1990).

Surfactants are classified into several types. Nonionic, cationic, silicone based, petroleum distillates and methylated or ethylated seed oils are the main types used in forestry. All reduce surface tension and cause droplet spread. The silicone-based surfactants reduce surface tension the most and hence cause the most droplet spread. However, this doesn't necessarily correspond to increased control (Fredrickson 1994, Whitson & Adam 1990, O'Sullivan et al. 1981). Many herbicides have adjuvants formulated into the product already. In many cases adding a surfactant to a product that already has a surfactant formulated into it adds no additional benefit (Fredrickson 1994, Brewster & Appleby 1990, Babiker & Duncan 1974).

Historically, non-ionic and silicone based surfactants were mainly used with water soluble amines. Petroleum or seed oil based adjuvants were primarily used with oil soluble esters. This has changed in recent times. The seed oil products tend to work well with either amines or esters. Adjuvants are usually cheap insurance but it shouldn't be taken for granted that they are increasing efficacy. Furthermore, surfactants can also have a negative effect on conifer tolerance (Fredrickson 1994).

Application Method

The application method you choose will also have an effect on the physical properties of the application, but mainly from a deposition standpoint. Treatments made by hand are going to directly deposit the spray solution exactly where it needs to go. The risk of offsite movement is minimal. Aerial applications have the most dispersion of the spray solution and while they can be applied extremely accurately, the deposition cannot be placed as accurately as hand applications. Ground applications with tractors or off road vehicles fall somewhere in the middle. The big tradeoff between the methods is cost, with hand applications being the most expensive and aerial applications being the least.

Application Methods

Aerial Applications

Aerial applications are the most efficient method of applying herbicides. Large areas can be treated in a very short period of time. Rough topography, poor access, lower cost, and large acreages are all factors that favor aerial applications. Generally, helicopters can carry eight to ten acres worth of material per load depending on the elevation. Fixed wing aircraft is only a possibility on very flat open ground. Where it can be used, it is more efficient than helicopter applications. Up to 50 acres per load can be applied with most fixed wing aircraft. The majority of the discussion here will concern helicopter treatments.

Targeting Vegetation with Aerial Applications

Developing prescriptions for aerial applications requires a good understanding of what can and can't be controlled by air. Since the quantity of material applied is less with aerial applications compared to hand treatments, the control of hard to kill brush species is more difficult by air. Herbaceous vegetation can be controlled equally as well by air or ground methods.

Herbaceous vegetation can be controlled with either foliar or soil active products. The difference is the duration of control. Any of the foliar chemicals such as glyphosate, triclopyr, 2,4-D, imazapyr, fluroxypyr or clopyralid will cause mortality of established herbaceous vegetation with aerial applications. With the exception of imazapyr, the other products have very little or no soil activity to prevent further germination. In this case herbaceous vegetation will rapidly re-occupy the site follow the application.

Using soil active products such as hexazinone, atrazine, sulfometuron methyl, oxyfluorfen or penoxsulam, the duration of control is extended by using chemicals that have residual activity in the soil. Hexazinone, atrazine, oxyfluorfen and penoxsulam have excellent conifer tolerance and can be applied as a pre or post plant application. Conifer tolerance issues with sulfometuron methyl prevent it from being used in the interior part of California, but applications on Coastal sites in the redwood range are possible. Hexazinone has the best knock down of emerged herbaceous vegetation. Atrazine and oxyfluorfen plus penoxsulam are best suited to pre-emergent applications unless another herbicide can be added. Knock down of existing herbaceous vegetation with oxyfluorfen plus penoxsulam is better than atrazine and can be improved with the addition of a methylated seed oil adjuvant.

Control of brush with aerial applications is a little more difficult. The size and type of brush, product and rate, timing, and adjuvant have major influences on control. Deciduous brush such as deerbrush (*Ceanothus integerrimus*) and snow berry (*Symphoricarpos albus laevigatus*) are fairly easy to control with applications of glyphosate. As deerbrush gets larger, control gets more difficult by air. This is true for most woody brush. Deciduous hardwood sprouts also prove difficult to control by aerial methods. They use of imazapyr alone or in combination with glyphosate dramatically improves control of larger woody deciduous brush and the addition of methylated or ethylated seed oils improves control further. Late summer timings of this treatment are usually better than earlier scheduling due to carbohydrate movement down into the root system later in the season. Due to conifer tolerance issues with imazapyr, only pre-plant applications are possible the year prior to planting, and seedlings still may show some symptoms of imazapyr damage. Deciduous brush and hardwood sprouts should usually not be treated with growth regulator products such as 2,4-D or triclopyr by air. These growth regulators cause rapid brownout of deciduous foliage and heavy damage to the translocating tissue in the plant. The result is rapid re-sprouting. Deciduous woody brush and hardwood sprouts treated in this manner, usually require re-treatment with a different method and product to achieve satisfactory control.

Evergreen brush such as tan oak (*Lithocarpus densiflorus*), golden chinquapin (*Chrysolepis chrysophylla*), greenleaf and whiteleaf manzanita (*Arctostaphyllos patula & viscida*, respectively), whitethorn (*Ceanothus cordulatus*) and snowbrush (*Ceanothus velutinus*) can be very difficult to control by air. Again, small plants are much easier to control by air than larger ones. Best control of evergreen brush is usually achieved with the oil soluble formulation of imazapyr (Chopper or Polaris AC) alone or in combination with glyphosate plus a methylated seed oil (MSO). These two systemic herbicides work incredibly well in combination. Both are ALS inhibitors, but they each inhibit three different amino acids (Ahrens 1994). Imazapyr inhibits valine, leucine and isoleucine, while glyphosate keeps the plants from producing tyrosine, tryptophan and phenylalanine. They both translocate very well within the plant and do very little damage to the translocating tissue. Coverage is usually the critical factor when aerial applications are used. Evergreen brush is easily controlled with this herbicide mix with hand applications, aerial treatments are usually less so but still acceptable.

Triclopyr ester, fluroxypyr and/or 2,4-D ester can also be used on the evergreen brush species, but results are slightly less acceptable than the glyphosate plus imazapyr combination. Applications of fluroxypyr and 2,4-D ester plus an MSO do control manzanita species well. Timing of application with evergreen species is a little different than deciduous brush. Early summer timings usually provide the best control with either the glyphosate and imazapyr combinations or growth regulator applications of 2,4-D, fluroxypyr or triclopyr esters. When applying the ester formulations of 2,4-D and triclopyr, volatility will be an issue if temperature exceeds much over 75 degrees. If temperatures are warm, these products should not be used near neighbors or crops as off site damage may occur.

Aerial Project Planning

The first part of any helicopter program is planning. Foresters must evaluate each site on a unit by unit basis to determine what units can be applied by aerial methods and which ones are better suited to ground treatments, as well as what herbicide prescriptions are needed. Most units can be applied by air unless there are a large number of water courses, sensitive areas or neighbor issues that limit the amount of ground that can be treated with a helicopter. From a cost perspective, large steep units with poor access are ideal for helicopter applications since hand treatments would be extremely cost prohibitive.

During initial site visits, foresters need to define unit boundaries, look for suitable heliports, water sources, access, any potential hazards or sensitive areas that need mitigation, and staging areas. Unit boundaries need to be clearly defined and very obvious. Usually clear cut boundaries are defined by the edge of mature timber or roads. However, in many cases such as when dealing with large burns with multiple land-owners, this often isn't the case. Unit boundaries, property lines, exclusion areas, etc may be difficult to see, especially when different landowners have treated their ground relatively the same. Defining property and boundary lines as well as exclusion areas can be done in several ways. Painting large spots (at least two foot diameter) with bright marking paint on rocks, stumps or logs about every 50 feet works well, especially with blue marking paint since it shows up well from the air. Large reflective pieces of foil or very heavy high visibility flagging can also be used. Remember, the pilot is going to be flying 50 to 100 feet above the ground traveling at roughly 50 mile per hour.

Suitable heliports can be difficult to find. Large landings work well provided they do not have any obstructions such as larger trees, saplings or landing piles to hinder ingress and egress. Heliports should have at least two clear directions for takeoff and landings. Helicopters prefer to take off and land into the wind so it helps to have multiple options. Ideally, having some slope also helps so that the helicopter can drop off the heliport. The heliports also need to be smooth and level. They also cannot be so dusty that the pilot's vision is impaired, and treating them with water during dry conditions may be necessary. Good access to heliports is a must as the batch truck will need to be within about 50 feet of the helicopter to fuel and load is with the spray solution. The number of heliports needed for the project depends on the size and number of units. A one mile radius should be roughly the maximum distance flown from each heliport unless there are no other options. Ferrying long distances is extremely expensive to the contractor, and if there are no other options, that needs to be made clear in the contract negotiation as it will affect the cost.

Ideally, the easiest way to obtain water for mixing is from a mill site, log yard, office or other property under your control. Creeks may be used, provided the drafting equipment on the batch truck is equipped with anti-backflow devices to prevent contamination. It is prudent to avoid drafting from streams or ditches where domestic water is obtained. It is always a good idea to test water sources for pH and cat-ions if you are unfamiliar with the sources, as high cat-ion contents indicated by a high pH can tie up some active ingredients in solution, thus affecting efficacy. Never batch near your water source. Whenever possible, batching should be done on the spray site.

The most critical thing foresters need to locate and define are the areas within the spray project such as water courses, springs, wells, domestic ditches, lakes, ponds, property lines or other resources that need protection. Once located, they should be mapped and well defined on the ground so that the pilot is fully aware of their presence. Resources can be protected using the mitigation measures discussed earlier in this chapter.

If the project occurs near residences or other neighboring land owners, it is a good idea to make contact with them ahead of time. A written neighbor notification program is a valuable tool for training foresters and improving their ability to communicate what you are trying to accomplish and addressing any concerns they may have. Many problems can be avoided through good communication. Showing up unannounced at their doorstep with a helicopter first thing in the morning is not the way to meet your neighbors.

Roads are the one aspect of a spray operation that is often over looked. All roads accessing the project area need to be driven before spraying operations occur. Roads need to be cleared of debris and have to be passable for a 4,000 gallon batch truck. Water bars need to be lowered or removed if present, and any rolling dips or other drainage structures need to be passable. Helicopter time and auxiliary equipment are extremely expensive, and unexpected delays can't be tolerated.

A secure area needs to be established for a staging area where the helicopter and batch truck can be located when not spraying. The area should be where the spray equipment can be watched or in an area where access is restricted to company personnel.

It is also very important for the forester to have chemical for the project delivered ahead of time to avoid potential delays. In favorable conditions, helicopters can apply as much as 600 acres in a day. Transportation and storage of chemical also needs to be addressed before the project starts. The storage area needs to be a locked secure placarded area. Any opportunity to minimize the distance to haul chemical to the project should be encouraged.

Accurate mapping is a necessity. Global positioning systems (GPS) and geographic information systems (GIS) should be used in conjunction as much as possible. Unit boundaries, roads, stream courses, protected areas and property lines should all be accurately mapped using GPS and downloaded directly into the GIS. Most helicopters today come equipped with some type of GPS guidance system. Shape files for layers from the land owners GIS system (unit boundaries, roads, stream courses, lakes, ponds, ditches, property lines) can be downloaded directly into the helicopters GPS system. The GPS system not only shows the pilot an accurate map of all the layers in the system, but maps the spray swaths and helicopter position as the application occurs. This provides a very nice, mapped record of what was and wasn't sprayed, including aerial buffers, exclusion areas and the unit itself.

Spray contracts need to be prepared and contain all the necessary information and instructions to complete a successful project. Contracts should include a unit summary and treatment list, price per acre or other unit, project maps, application parameters, acceptable weather conditions, weather and application record keeping requirements and forms, licensing requirements, mitigation measures to follow, production schedules, chemical handling and transportation procedures, use reporting guidelines, container disposal guidelines and any other pertinent guidelines or information.

Aerial Project Implementation

When the aerial project is ready to begin, there are several things to consider. It is very helpful and wise to have two to three people working with the forester in charge of the project in the field. These extra people can be used to check weather conditions on units in advance of spraying, make sure units are clear of people, block access into the spray area, lead equipment in and out of spray units and keep weather records. By knowing what the weather conditions are on units yet to be sprayed, the project manager can efficiently move from one spray area to the next, saving valuable time and money.

When the helicopter arrives, it is pertinent to go over the spray plans, herbicide mixes, application volumes, mitigation measures, policies and calibration with the pilot and batch truck driver. Making sure the helicopter is calibrated prior to starting is critical to achieve the desired application rates. For reference on aerial calibration see Dreistadt (2013). Check the nozzle setup on the helicopter and make sure it is acceptable for your objectives. Based on the contract specifications, the helicopter should be set up the way you want it, but don't take it for granted.

Batching should be done on the spray unit at the start of each day to minimize traveling with a load of chemical in the batch truck. By batching on the unit, this also gives you an opportunity to assess weather conditions and batch the amount for what you think you can easily finish. When possible, it's best to avoid letting chemical sit over night in the spray tank. This will reduce problems with settling in the tank and potential vandalism issues.

Determining where to start your project may not make a difference much of the year, but occasionally in the fall with large projects bad weather can influence your program. In this case it is usually a good idea to start in the highest elevations first and work down in case snow becomes an issue. The opposite is true with large projects in the spring. Working from low to high usually makes the most sense as snow melts. One of the important things foresters will learn over time are the local weather patterns. This can save an inordinate amount of time and money figuring out where to start each day. Usually the wide temperature swings during the California day causes dramatic changes in wind patterns and direction. Before and after storm fronts pass through also bring in their own set of wind patterns. While all of this can effect spray operations, the patterns are fairly predictable.

Before starting to spray, the forester should recon the units with the pilot. The forester should show the pilot unit boundaries, water courses, property lines, sensitive areas, and anything else of concern. The forester can also give any special instructions such as when and where to utilize a split boom. The forester should also document the instructions given to the pilot in their daily spray records. Written notes are critical documentation in the event one ever gets taken to court over a spray application.

Finish spraying one unit before starting the next. As part of the forester's record keeping, each load and volume taken should be kept track of for each unit. It is imperative to know how much spray volume went on each unit. If the pilot is flying more than one unit at a time accurate records of how much volume went on each can not be kept. Keep in contact with the pilot during the application, but try and keep radio traffic to a minimum.

Be observant during the spray operation. Watch as creeks and drainages are flown to assure proper buffering is done and split boom applications are used. Make sure all the nozzles on the boom are working. Keep a watchful eye out for people or vehicles entering the spray area.

Accurate record keeping is invaluable. It allows you to keep track of the herbicide volume used, time, rates, mitigation measures used, costs, weather conditions and personnel. At a minimum, the forester should have two data sheets for record keeping. One for weather and one for each units spray record. At a minimum, the weather should be taken at least every hour, if not more and include time, wind speed and direction, temperature and humidity. The pilot is required to have weather records under California law. The unit summary data should include the unit name or number, acres, personnel present, contractor, herbicides used and rates applied, volume per acre, mitigation measures used, number of loads flown, volume used per load, total gallons flown, the time each load was flown, pilot name, and any other application notes pertinent to the job.

Hand Applications

A very expensive part of any reforestation effort is the labor cost of hand spraying. There are many application techniques and types of equipment that will help improve efficiencies and reduce costs. Making effective and efficient applications by hand is an art. As a result, hand spray labor is a very important area for a reforestation forester to focus their effort on when it comes to reducing costs. The more intimately familiar the forester becomes with the tools and techniques to operate efficiently and effectively, the more valuable the forester will be.

Having the Right Equipment

Usually hand spray crews are made up of 10 to 14 people. Any time the crew is waiting around and not spraying is extremely costly. Efficient application equipment should be built around the concept of reducing that time. If a crew has to spend much time waiting around for more water, or walking back to the batch truck to fill up their backpacks, costs can skyrocket.

The batch truck and associated equipment are the key to reducing costs in the field. Batch trucks should be set up with a spray tank large enough to carry a good supply of chemical. Five hundred gallon tanks are a good size. One of the real keys to reducing down time is to have a good supply of water. A water tender trailer is essential to reduce application costs. To work with the batch truck, a trailer fitted with at least a 750 gallon tank for water only is generally enough to supply a crew for an entire day. The water trailer should also be fitted with lockable metal storage bins to carry chemical, drafting equipment and other spray equipment. Drafting equipment should be kept in a separate storage container that is chemical free. Never put contaminated equipment into a water source to draft from. Storage containers need to be large enough to carry several 30 gallon containers of chemical. Having enough chemical on board to last several days will also help reduce costs dramatically.

Reducing the amount of time a crew spends walking without spraying is the key to reducing costs. Often times, reforestation units are large and when crews run out of spray solution in their backpacks, the time required to walk back to the batch truck to fill up can be substantial. Any efficient spray operation should have batch trucks set up with a power take off driven hose reel and pump system to bring the chemical to the crew instead of the crew to the chemical. A hose reel capable of holding at least 1200 to 1500 feet of high pressure hose and having the ability to pump uphill as well as down can save large amounts of time that would otherwise be spent walking. The hose reel itself needs to be set up with a power reel up system as hose with a full load of chemical can be extremely heavy. Usually hydraulic powered systems are best.

Good communication between the crew foreman and the batch truck driver is essential. Each should have a portable radio that the foreman can use to tell the batch truck where to move the truck to and when to pull or reel up the hose lay. This will also save a substantial amount of time.

In certain instances such as large wildfires with poor access it helps to have an off road vehicle equipped with a spray tank and delivery system to fill backpacks in the field. In remote areas where hose reels can not supply enough hose to reach the crew, an off road vehicle may provide an efficient alternative.

Managing access to units is critical. Too often roads that provide access to reforestation units are decommissioned immediately after logging operations cease. It is imperative to communicate with logging managers and plan writers the importance of leaving access to units open at least until the reforestation efforts are finished, which may be several years. Poor access will affect the cost of all reforestation activities, not just spraying.

Spray crews must be supplied with a wide variety of application equipment to achieve the desired objectives of the forester. Besides the standard backpacks and spray wands, crews should be trained and have the equipment to do broadcast, spot-gun, gun-jet and hack and squirt applications. A supply of meter jets, gun-jets, hatchets, and backpack injectors should be available. Having an extensive selection of nozzles including flat fans, off center and adjustable tip nozzles will also allow for a wide flexibility in the types of applications crews can do.

Directed Hand Spray Applications

Hand applications can consist of two types, broadcast applications where 100 percent of the ground area is treated at a specific rate per acre or some type of individual plant treatment. The first type of individual plant treatment discussed will be directed spray applications. This is the most common type of application used to control difficult woody brush. With this treatment individual plants are sprayed with a standard backpack and wand usually equipped with a flat fan nozzle. Nozzle types and characteristics are discussed in detail earlier in this chapter. The larger the orifice and angle of flat fan nozzles, the larger the drop size and wider the swath, respectively. Narrower angle nozzles give the applicator more control over what plants are covered. Occasionally, adjustable tip nozzles can be used for taller brush such as hardwood sprouts which allows the applicator to reach up higher on the plant.

Directed spray applications are used when the herbicide cannot be applied over the top of existing conifer seedlings without injury. In these types of applications, protection of the seedlings is necessary to prevent damage. Usually some type of shield with a handle is carried by each applicator. Seedlings are covered with the shield while the applicator sprays the vegetation around the tree, avoiding any contact.

With directed spray applications, it is very important to know what the target volume per acre should be. There are two reasons for this. The first is that you want to make sure that maximum label rates are not exceeded. Second, as volume per acre increases, crews slow down and hence, costs increase. By observing the crew spray a small known acreage at the beginning of the project, the forester can determine the volume per acre and adjust accordingly. It is a good idea to observe the spray pattern so the forester can tell by looking in the future whether crews are applying too heavy or too light. With directed applications, the use of dye is required to see what has and hasn't been sprayed.

Directed spray applications are usually batched on a percent solution basis. When that is the case, the forester needs to convert from percent solution to a rate per acre to determine if the application is being applied within the designated prescription rates. For example, if the maximum rate per acre of a given herbicide was one quart per acre and the crew was applying the mix at a 25 gallon per acre spray volume, the percent solution rate could not exceed one percent to avoid going over the maximum label rate. To adjust the volume per acre, nozzle size could be adjusted or the crew members could adjust the volume they are putting on each plant.

When planning directed spray projects, keeping costs to a minimum is essential. The smaller the brush, the less volume that is going to be applied and the cheaper it will be for labor and chemical. The crown volume of woody brush grows at an exponential rate from year to year. By delaying spray projects until brush gets large and dense, application costs can easily reach several hundred dollars per acre in just labor. Small seedling brush can be more easily controlled at a lower labor cost and a lower volume of herbicide applied. However, foresters need to be careful not to treat woody brush that has sprouted from old root systems too early before the plants have been able to put on enough crown to absorb enough chemical to control the existing root system.

Herbaceous vegetation treatments are usually not done using directed spraying with one exception. Occasionally landowners may want to apply glyphosate as a foliar treatment post-planting to control herbaceous vegetation. In this case, the glyphosate must be applied as a directed treatment since freshly planted conifer seedlings are not tolerant to over the top applications. Since there is no soil residual activity, residual weed seeds will not be controlled if the application is made before they have germinated. Likewise, if the application is made after the germinated plants have set seed, the new seed will then be present to germinate in subsequent growing seasons. For these reasons, the control of herbaceous vegetation using glyphosate needs to be critically considered and carefully timed. Longer lasting herbaceous treatments can be applied as a broadcast treatment with hexazinone, atrazine, sulfometuron methyl, or oxyfluorfen plus penoxsulam either as a pre or post plant application, unless conifer tolerance or company directives dictate otherwise.

Directed spray treatments can be used very effectively around sensitive areas such as water courses, lakes, ponds, property lines and other sites needing protection. Herbicides can be placed very accurately with this method with very minimal risk of off-site movement.

Broadcast Hand Treatments

The most efficient delivery method for herbicides by hand is applying them as a broadcast treatment, similar to a helicopter application. With broadcast applications, 100 percent of the ground area is treated in a systematic calibrated fashion. Depending on the conifer tolerance of the herbicide used, broadcast treatments may be applied pre or post plant. Broadcast applications are the most cost effective application method by hand. Depending on the type of equipment used, application costs can come close to that of a helicopter.

There are several methods that can be used to apply broadcast treatments. Boom spraying is a possibility, but not very practical with a large crew and requires a larger volume of spray solution than an individual can usually carry to be cost effective. Therefore, we will not discuss it here.

Most of the broadcast treatments are applied with what is known as the waving wand technique (Newton 2009). The technique can use either a conventional spray wand or a gun-jet application system. The wand is waved side to side at moderate speed so that the stream from the nozzle overlaps creating a solid swath as the applicator moves forward. To apply this method properly, the applicator must know the width of the swath they are producing, wave rapidly enough that coverage is solid, and calibrate the walking speed to achieve a target volume per acre.

The crew must be calibrated prior to making the application. To calibrate the waving wand method, first stand in one spot and spray, waving back and forth until the effective swath is visible on the ground. Measure the effective swath width. Then take a measured amount of water (one gallon) and put it in the backpack. Walk at a comfortable pace that can be maintained across an entire spray unit. Spray out the one gallon of water walking at the chosen pace waving the wand back and forth exactly as it was done to measure the swath with. Measure the distance traveled from where spraying started to when the backpack ran out of water. Calculate the area covered in square feet (swath width (ft) x distance traveled (ft)). Divide that number by 43,560 (square feet in an acre) to get the percentage of an acre sprayed. Divide the percentage of an acre sprayed into the volume sprayed out (in this example one gallon). That will tell you how many gallons per acre of spray solution you put out at that walking speed. That walking speed and waving technique must be replicated by all of the crew members and they must be spaced apart evenly so as to not overlap swaths too much or too little. Not being properly calibrated or trained in the application procedures can result in the wrong rates being applied, conifer injury or excessive skips left across the spray unit. This method is highly effective and efficient, but should only be applied by a properly trained and very experienced crew.

It is important to distinguish the difference between volume of solution applied per acre and the rate per acre of whatever herbicide you are using. In general, five to ten gallons per acre is the normal volume of solution applied (water and chemical) with waving wand applications depending on the method used. The rate per acre of herbicide is designated separately. For example, you can apply two quarts per acre of a glyphosate product in either five or ten gallons per acre of total solution. The two quart glyphosate would remain the same, but the dilution would change.

Several types of application setups can be used. For maximum production, gun-jet applicators can be used. This wand looks much different than a typical backpack wand and uses a disc nozzle similar to what is used in helicopter applications. The gun-jets have an adjustment where the spray output can be set at a straight stream down to a fine mist. The proper setting is to open the nozzle all the way so that it emits a straight stream and then begin to close it down to the point where the stream is just starting to become fractured. When waved side to side, swath widths of up to 30 feet can be achieved. Care must be taken to point the gun-jet away from the applicator as they walk so that they are not walking into the spray material. The gun-jet system is more suited for soil active herbicides as coverage is slightly variable. It is also highly sensitive to wind and worker exposure can be an issue if not properly applied. Adjustable tip nozzles can also be used with a normal spray wand that simulates a gun-jet application, but production and swath width are slightly less. This method is slightly slower, but is a little more forgiving regarding working exposure and drift.

The most effective and controllable waving wand application method is the off center nozzle system. In this case, a normal spray wand is utilized, but fitted with an off center nozzle (OC nozzle). This nozzle puts out an elongated spray pattern that when waved side to side provides superior coverage over any other waving wand method. It is also the method with the least applicator exposure, as the nozzle spray pattern is pointed downward and thrown away from the applicator as it is applied. This method can be used for either foliar or soil active products. Smaller orifice off center nozzles should be utilized for foliar applications for better coverage. Swath widths are reduced to about 12 to 15 feet with off center nozzles compared to the gun-jet system, but production rates are only slightly less. Swath width and walking speed increase as the size of the nozzle orifice increases. Hence, application costs are reduced with increasing nozzle size.

Topography can severely affect the pace of the spray crew when doing waving wand applications. Inherently, crews slow down on steep slopes or in units with heavy slash loads. The forester and foreman need to be aware of changing conditions that may affect the volume per acre applied. Changing nozzle size is a good way to deal with changes in topography. Using smaller nozzles on steeper slopes or units with heavy slash will adjust for a slower walking pace and maintain the same volume per acre used on easier ground.

One other limitation of the waving wand method is the height and density of brush. When brush gets more than about three or four feet tall and dense, waving the wand gets exceedingly difficult. Pace is more difficult to maintain, as is keeping the crew members together. To do these applications effectively, crew members need to stay together and keep in an organized line so that each one can see where the next has sprayed. The last applicator in line or the foreman, needs to flag the outside spray line so the crew knows where to follow back on when they turn around to make another pass.

A well trained crew in broadcast application techniques is an invaluable asset to a reforestation forester. Application costs can range as low as 25 to 45 dollars per acre for labor depending on the application and site. This is not the application type that you want to contract out as a low bid application. Broadcast applications by hand are very complicated and results can be poor if not applied properly. Foresters need to be aware that crews can cover a large amount of acreage in one day, and if not applied properly, the results could be very costly.

Hack and Squirt Applications

Hardwood trees and sprout clumps are extremely competitive to young conifer seedlings in California (Jackson & Lemon 1988). Sprouting hardwoods from cut stumps can occupy large areas within a reforestation unit in a very short amount of time, depriving seedlings of valuable light, nutrients and water (DiTomaso, Keyser & Fredrickson 2004). Where hardwood populations are heavy, reforestation units could be entirely dominated by hardwood cover if not managed to some degree. It is wise to designate a certain number of hardwood trees and clumps for retention for wildlife concerns, but if left totally unmanaged this can cause significant problems for reforestation efforts.

Hack and squirt applications are one of the most important techniques we have for managing hardwoods. It is a very selective technique that allows for managing hardwoods at whatever density the land manager chooses. It is a fairly simple but extremely efficacious, efficient and cost effective treatment.

The tools required are a hatchet, a small gravity fed backpack and a calibrated veterinary syringe capable of delivering a specific amount of liquid (Figure 8.4). The veterinary syringe can be set to a specific amount of chemical to inject. In most cases the delivery amount is set at either one half or one full milliliter of liquid. The number of hacks made per tree is determined by using either a specific spacing around the circumference of the tree or designating one hack for every so many inches of tree diameter at breast height (Figure 8.5). For example, using circumference, a hack could be placed every six inches around the circumference of the tree. When using diameter as a guide, a tree could be injected using one hack per every three inches of diameter at breast height. In this case a 9 inch tree would receive three hacks. Once hacked, the appropriate amount of chemical would be injected into each hack using the veterinary syringe. The chemical is usually used undiluted.

In the case of treating hardwood clump sprouts where the stems are too small to hack on a circumference or diameter basis, the number of injections is usually determined by selecting a certain number of stems to inject per clump. Stems may either be hacked with a hatchet if large enough or snapped by hand and the chemical injected into the broken stem.

Trees and clump sprouts can be injected almost all year long, however spring treatments are not recommended when sap is flowing. At that time, chemical injected into the cuts can be pushed out of the hack area to the extent that it makes the treatment ineffective. Big leaf maple will begin flowing sap as early as late January in northern California. The most effective timing is usually late summer through the entire winter for most hardwoods (Ditomaso, Keyser & Fredrickson 2004).

The most widely used herbicide for injection treatments is imazapyr, and it is without a doubt the most effective. Conifer tolerance precludes its use as a release treatment in many situations, but it is ideal as a treatment for pre-harvest site preparation or pre-plant site preparation which will be discussed later in this chapter. It is important to realize that imazapyr does have soil activity and translocates very well with plant systems. Many hardwood species that are growing in close proximity to one another are known to form root grafts. Any tree that is root grafted to a treated tree may show visible symptoms or even death. This is an important consideration when treating near property lines. Buffer zones may be needed to prevent inadvertent mortality across property lines or to trees intended to be retained for wildlife features (Ditomaso, Keyser & Fredrickson 2004). Imazapyr may also be exuded through the roots of treated trees into the soil where conifer seedlings could absorb it and be damaged.

One of the benefits of having a hack and squirt program is that crews can operate when windy or other weather precludes them from foliar spraying. The only weather condition that will prohibit hack and squirt applications is heavy rain as freshly injected chemical may be washed out of the cuts. Planning the total application program with the option of utilizing the crew for hacking when weather prohibits other application methods will provide a more consistent supply of work.

Application costs depend on the density and type of hardwood treatment. Labor costs with tree hack and squirt in the interior part of California in typical black oak (*Quercus kelloggii*) stands usually averages somewhere between 20 and 50 dollars per acre. Hack and squirt treatments on the Coast of California can be much higher due to heavy densities of tan oak (*Lithocarpus densiflorus*), as can stands with dense under-stories of other hardwood sprouts. Herbicide rate per acres needs to be closely monitored in stands that have very high stem densities as the maximum rate per acre could easily be exceeded.

Treating hardwoods prior to planting is much preferable than post-plant treatments. Benefits usually include lower costs, better conifer tolerance and better efficacy.

Cut Stump Treatments

Cut stump treatments are seldom utilized in forestry due to cost and the ability to use other more efficient and effective methods. Trees or brush can be treated with this method. Plants are treated by severing the stem or bole with a chainsaw or other cutting tool and then using a squirt bottle to apply either a high concentration solution or undiluted herbicide around the cambium of the stump. Herbicide need not be applied to the deadwood in the center of the stump. The key to applying cut stem treatments is to treat the stumps immediately after cutting because delaying the application will dramatically reduce translocation and efficacy.

Several herbicides can be used with cut stump applications. Triclopyr, glyphosate and imazapyr are the three that are most commonly used. It is imperative with triclopyr in warm weather to make sure that the amine formulation is used as the ester formulation will volatilize. Care must be taken with imazapyr if stumps are treated along property lines or right of ways where adjacent vegetation may be root grafted to treated stems. Cut stump applications are generally most effective in the late summer to winter, but may be treated most times of the year other than during spring sap flow.

The major deterrent to cut stump treatments is the labor cost associated with cutting of the vegetation. Chainsaw removal of large brush may cost as much as 300 to 400 dollars per acre in dense stands. These treatments are often used when brush is too tall to foliar spray but the land manager wants to treat the vegetation before clearing the ground for planting to avoid

re-sprouting. In the instance where vegetation is so large that it can not be foliar treated before mechanical site preparation activities occur, it may be more cost effective to pile the vegetation first and manage the re-sprouting vegetation. In general, it is best to treat the vegetation prior to removal to maximize efficacy and reduce costs.

Basal Bark Treatments

Basal bark treatments are used primarily to control re-spouting hardwoods and larger woody brush. The herbicide solution is applied to the bark of the lower stems of plant, near the ground line. Triclopyr ester and imazapyr are the main herbicides used with basal treatments. With basal applications, the herbicides are mixed with a basal bark oil as the carrier instead of water to get penetration through the bark. Bark thickness increases as plants get older and therefore, basal treatments are limited to stems with a maximum ground line diameter of three inches or less.

There are three types of basal bark applications - conventional, low volume and thin-line basal treatments. With convention basal treatments, stems of treated plants are sprayed around the entire circumference of each stem from the ground line up to a height between 18 and 24 inches depending on the preference of the land manager. It is very important to completely cover the circumference of every stem and to heavily cover the root collar area on the stump to insure control. Low volume basal treatments are applied in the same way, but the herbicide concentration is significantly higher than what is used with conventional basal treatments and the stems are only treated to a height of six inches above the ground line, reducing the total volume used.

Thin-line treatments are still applied to the base of the stems but in a much different way. Thin-line uses the highest concentration of solution of any of the methods, but also the lowest volume. The spray solution is applied through a nozzle that produces a straight stream. The stream is arced across the base of the stems from left to right to a height of about one foot above the ground line from three or four sides of the plant. The idea is to connect all of the arcs so that all stems receive some coverage. Unlike conventional or low volume basal treatments complete coverage around the entire circumference of the stem is not necessary due to the concentration of herbicide solution.

Labor costs are the most expensive for the conventional basal treatments followed by the low volume treatments, with thin-line treatments being the least expensive. The efficacy of basal bark treatments vary dramatically by geographic region. In the interior parts of California, basal treatments do not typically work as well as other treatments designed to treat hardwood sprouts such as foliar or hack and squirt treatments with imazapyr. Heavy re-sprouting usually occurs with basal applications on species like black oak (*Quercus Kellogii*) and dogwood (*Cornus nuttallii*). In Oregon, basal treatments with triclopyr ester are the most effective method on species such as tan oak and big leaf maple (*Acer macrophyllum*) (Gourley personal communication).

Spot-Gun or Meter-Jet Applications

Spot-gun and meter-jet applications are one and the same and will be referred to as spot-gun for the rest of this text. This is a very efficient application technique for controlling various types of woody vegetation that are sensitive to the herbicide hexazinone such as snowbrush (*Ceanothus velutinus*), whitethorn (*Ceanothus cordulatus*), deerbrush (*Ceanothus integerrimus*) or greenleaf manzanita (*Arctostaphyllos patula*). Spot-gun treatments are applied using a Meter-jet application system to individual plants or on a grid system if plant cover is too heavy to treat individual plants. The device delivers a measured amount of chemical with each pull of the trigger and can be adjusted to deliver a range of rates. The herbicide is applied undiluted to the soil about midway between the root collar and the branch tips. Generally, three milliliters of the liquid formulation of hexazinone per spot is applied. The number of spots a plant receives is dependant upon the size of the plant. Most plants receive a minimum of two spots. The spot where the herbicide is applied must be free of litter or other debris that may tie up the chemical.

This application system requires an experienced crew to properly apply the treatment. Crews must be careful not to exceed the maximum label rate. Crop trees may be damaged or killed if too much hexazinone is applied in any given area. If the vegetation is too heavy to treat individual plants and a grid system must be used, another treatment method should probably be considered as grid applications are not nearly as effective. Spot-gun applications are best suited to low brush densities. Conifers can also be severely injured or killed in stands adjacent to treated areas as root uptake occurs. Large cedars and sugar pines are at the highest risk in close proximity to the treatment area and may be killed if not given a large enough buffer. It is also important to adjust the spot placement when treating on steep slopes. Spots should be placed around the upper sides of the plant so the herbicide does not move down slope away from the root system.

Rainfall is required to activate the hexazinone. The majority of spot-gun applications are applied in the fall as the main target is snowbrush which occurs in the upper elevations. It is important not to get too much or too little precipitation for the herbicide to work correctly. Generally, between three and twenty inches of rain is desired for effective hexazinone applications. Lower elevation species such as deer brush could theoretically be treated in the spring if an adequate moisture window still exists. Spot-gun applications are highly effective and very efficient from an application standpoint. The cost per acre is generally very low and labor costs usually range between $25 and $35 per acre.

Tractor or ORV Applications

Opportunities to utilize tractor or ORV mounted spraying systems in forestry are minimal. Usually terrain, stumps, brush, rocks, snags and residual conifers prohibit efficient use of such systems. There are instances where it may be possible such as roadsides, pasture conversions or very flat and clean clear cuts relatively free of slash.

Where it is possible, the applications are similar to aerial traetments. They are primarily broadcast applications to be applied at a certain volume per acre with the potential exception of roadside applications. In this case, calibration of the system and traveling speed is critical (see Dreistadt 2013 for calibration of tractor mounted systems). The choice of herbicides used will depend largely on what vegetation is present on the site and whether or not conifer seedlings have been established. Pre or post plant applications can be made with a tractor or ORV system provided tree height and conifer tolerance is not an issue.

The delivery system for these applications is primarily through a mounted boom. For forestry applications shorter booms are better. Unique configurations of flood-jet and off-center nozzles could also be used to reduce boom lengths and increase the maneuverability in reforestation units. Roadside applications usually either have a hand-held nozzle system mounted to the spray or a half-boom with off-center or flood-jet nozzles to treat roadsides.

The main benefits of tractor or ORV mounted systems is control of the spray deposition. The spray solution can be accurately placed along stream buffers, property lines and other sensitive areas to make sure contamination does not occur. Application costs are relatively cheap and are along the lines of broadcast hand applications.

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References

Ahrens, W.H. Editor. 1994. Herbicide Handbook-7th Edition. Weed Science Society of America. Champaign, Il. 352 P.

Akesson, N.B., R.E. Cowden and W.E. Yates. 1985. Atomization of Herbicide Simulants with Hollow Cone and Raindrop Nozzles. USDA Forest Service. Forest Pest Management.
FPM 85-1. 103 P.

Akesson, N.B., W.E. Yates and S.E. Wilco. 1970. Key to safe and Effective Aerial Application: Controlling Spray Atomization. Agrichemical Age. December. Pp 10-17.

Allen, B.H. and J.W. Bartolome. 1989. Cattle Grazing Effects on Understory Cover and Tree Growth in Mixed Conifer Clearcuts. Northwest Science. 63(5): 214-219.

Ambach, N.H. and R. Ashfored. 1982. Effects of Variation in Drop Make-up on the Phytotoxicity of Glyphosate. Weed Science. 30:221-224.

Arno, S. F., M.G. Harrington, C.E. Fiedler and C.E. Carlson. 1996. Using Silviculture and Prescribed Fire to Reduce Fire Hazard and Improve Health in Ponderosa Pine Forests. Proc. 17th Ann. Forest Vegetation Management Conference. Redding, Ca pp. 114-118.

Babiker, A.G.T. and H.J. Duncan. 1974. Penetration of Bracken Fronds by Asulam as Influenced by the Addition of Surfactant to the Spray Solution and by pH. Weed Reasearch. 14: 375-377.

Barry, J. W. 1984. Drop Size: Drift and Effectiveness of Herbicide Sprays. Forest Vegetation Management Workshop. Oregon State University. July 17-19. pp 1-22.

Beaudry, P.G. 1990. Downslope Movement of the Herbicide Hexazinone in the SBS Zone. B.C. Ministry of Forests. December 1990.

Brevis, Juan C., T. Lanini, K. Giles, D.C. Slaughter, D. Downey and C. Gliever. 2004. Weed Control Using a Prescision Application System with Image Vision. Proc. Cal. Weed Sci. Soc. 56: 139-140.

Brewster, B.D. and A.P. Appleby. 1990. Effect of Rate, Carrier Volume, and Surfactant on Imazamethabenz Efficacy. Weed Technology. 4: 291-293.

Buhler, L. and O.C. Burnside. 1987. Effects of Application Variables on Glyphosate Phytotoxicity. Weed Technology. 1:14-17.

Busse, M.D., N.G. Rapaport, and R.F. Powers. 2000. Tolerance of Soil Organisms to Herbicide Applications in Ponderosa Pine Plantations. Proc. 21st Ann For. Veg. Mgt. Conf. Redding, Ca. pp 33-38.

Chandran, R.S. and L.W. Jett. 2009. Weed Management in Vegetables. West Virginia University Extension. Extension Bulletin. 2009.

Chase, C. A., J.M. Scholberg and G.E. MacDonald. 2004. Preliminary Evaluation of Nonsynthetic Herbicides for Weed Management in Organic Orange Production. Proc. Fla. State Hort. Soc. 117:135-138.

Coates, K.D., M.J. Douglas, J.W. Schwab and W.A. Bergerud. 1993. Grass and Legume Seeding on a Scarified Coastal Alluvial Site in Northwestern British Columbia: Response of Native Non-Crop Vegetation and Planted Sitka Sprice (Picea sitchensis(Bong.) Carr.) Seedlings. New Forests. 7:193-211.

Cole E.C. and M. Newton. 1989. Seasonal Efficacy Comparison of Two Glyphosate Formulations. Proc. Western Soc. Of Weed Sci. 42:136-141.

Craig, S. and J. McHenry. 1988. Mulch Collars for Preventing Vegetation Around Conifer Seedlings: A Test of Several Methods. Proc. 9th Ann For. Veg. Mgt. Conf. Redding, Ca. pp 142-150.

Crammer, J.R. and D.L. Lindscott. 1990. Droplet Make-up and the Effect on Phytotoxicity in Glyphosate. Weed Science. 38:406-410.

Curran, W.S., D.D. Lingenfelter and C.B. Muse. 2005. Effectiveness of Vinegar and Clove Oil for Control of Annual Weeds. Poster Session. Weed Science Society of America. 2005. 1 P.

D'Anjou, B. 1990. Growth Response of Several Vegetation Species to Herbicides and Manual Cutting Treatments in the Vancouver Forest Region. FRDA Report #135. B.C. Ministry of Forests. 6 P.

DiTomaso, J.M., G.B. Kyser and E.A. Fredrickson. 2004. Control of Black Oak and Tan Oak in the Sierra Nevada Range. W. Jor App. For. 19(4):268-276

Dreistadt, S.H. 2013. Forest and Right of Way Pest Control. Second Edition. University of California. ANR Pub 3336. 340 P.

Evans, Glenn J. and R.R. Bellinder. 2009. The Potential Use of Vinegar and a Clove Oil Herbicide for Weed Control on Sweet Corn, Potato and Onion. Weed Tech. 23(1): 120-128.

Fan, Z., J.A. Moore, B. Shafii and H.L. Osborne. 2002. Three Year Responses of Ponderosa Pine Seedlings to Controlled Release Fertilizer Applied at Planting. West. J. Appl. For. 17(3): 154-164.

Fiddler, G. O. and P.M. McDonald. 1997. Mechanical and Chemical Release Applied to a 12 Year Old Pine Plantation. USDA Forest Service. Pacific Southwest Forest and Range Experiment Station. Research Paper. PSW-RP-232. 12 P.

Fiddler, G. O. and P.M. McDonald. 1999. Treatment Duration and Time Since Disturbance Affect Vegetation Development in a Young Ponderosa Pine Plantation. USDA Forest Service. Pacific Southwest Research Station. Research Note. PSW-RN-424. 8 P.

Fiddler, G. O., P.M. McDonald and S.R. Mori. 2000. Mechanical and Chemical Release Applied to a 16 Year Old Pine Plantation. USDA Forest Service. Research Note. PSW-RN-425. 10 P.

Fisk, J.N. 1984. Estimating Effects of Competing Plants on Conifer Growth and Yield, and Determining Release Needs. Proc. 6th Ann. For. Veg. Mgt. Conf. Nov 1-2, Redding, Ca. pp. 129-143.

Fredrickson, E. A. 1994. Efficiency of Forest Vegetation Control with Herbicides. Oregon State University. M.S. Thesis. 204 P.

Fredrickson, E.A. and M. Newton. 1998. Maximizing Efficiency of Forest Herbicides in the Sierra Nevada and Oregon. User Guide. Corvallis, Or. Oregon State University. Research Contribution 19. 45 P.

Fredrickson, E.A. 2002. Fall Planting in Northern California. USDA Forest Service. Rocky Mountain Research Station. Proc. RMRS-P-28. pp 159-161.

Fredrickson, E.A. 2004. Pre-Harvest Site Preparation with Herbicides. Abstract. 25th Ann. For. Veg. Mgt. Conf. Redding, Ca. p. 79.

Fredrickson. E.A. 2005. The Influence of Initial Stock Size on Seedling Survival and Growth. Presentation for the 26th Ann. For. Veg. Mgt. Conf. Redding, Ca.

Fuller, J. L. 2002. Assessing the Safety of Biological Weed Control: A Case Study of the Cinnabar Moth. M.S. Thesis. Oregon State University. 59 P.

Fullmer, D.G. 1986. Sheep Grazing for Plantation Release: A Foresthill Ranger District Case Study. Proc. 8^{th} Ann. Forest Vegetation Management Conference. Sacramento, Ca. pp. 149-163.

Gratkowski, H. and R. Stewart. 1973. Aerial Spray Adjuvants for Herbicide Drift Control. USDA Forest Service. Pacific Northwest Forest and Range Experiment Station. General Technical Report. PNW-3. 18 P.

Harper, G.J., P.G. Comeau and B.S. Biring. 2005. A Comparison of Herbicide and Mulch Mat Traetments for Reducing Grass, Herb and Shrub Competition in the BC Interior Douglas-Fir Zone-Ten Year Results. West. J. Appl. For. 20(3): 167-176.

Harrington, T. B. and S.D. Tesch. 1992. Manual Cutting In Forest Vegetation Management. Proc. Forest Vegetation Management Without Herbicides. Oregon State University. pp 112-117.

Haywood, J. D. 1999. Durability of Selected Mulches, Their Ability to Control Weeds, and Influence Growth of Loblolly Pine Seedlings. New Forests. 18: 263-276.

Haywood, J. D. 2000. Mulch and Hexazinone Herbicide Shorten the Time Longleaf Pine seedlings are in the Grass Stage and Increase Height Growth. New Forests. 19:279-290.

Helms, J.A., C. Hipkin, and E.B. Alexander. 1986. Effects of Soil Compaction on Height Growth of a California Ponderosa Pine Plantation. West. Jor. App. For. 1: 104-108.

Hess, D. and R.H. Faulk. 1990. Herbicide Deposition on Leaf Surfaces. Weed Science. 38:280-288.

Hollaway, J.K. 1964. Projects in Biological Control of Weeds. P. Debach editor. Biological Control of Insect Pests and Weeds. Reinhold Publishing Corp. New York. pp 650-670.

Hudson, B.D. 1994. Soil Organic Matter and Available Water Capacity. Jor. of Soil and Water Cons. 49(2): 189-194.

Isaacson, D. and M.H. Brooks. 1999. Weed Control: Extended Abstracts from the 1997 Interagency Noxious Weed Symposium. USDA Forest Service FHTET-98-12, June. 59 P.

Jackson, N.E. and M.D. Lemon. 1986. Timing of Application Studies with Roundup Herbicide for Control of Bear Clover (*Chamaebatia foliolosa*) in California Forestry. Proc. 8^{th} Ann. For. Veg. Mgt. Conf. Nov 5-6. Sacramento, Ca. pp. 113-119.

Jackson, N.E. and M.D. Lemon. 1988. *Roundup herbicide for control of bear clover (Chamaebatia foliolosa) in California forestry*. Paper presented at the 8th Annual Forest Vegetation Management Conference.

Johnson, S.A. 1987. Pronone Herbicide: A Granular Hexazinone Formulation for Site Preparation and Conifer Release. Proc. 9^{th} Ann. For. Veg. Mgt. Conf. Nov 3-5. Redding, Ca pp:34-42.

Kauffman, J.B. 1992. Prescribed Fire in Forest Vegetation Management: A Research Synthesis. Proc. Forest Vegetation Management Without Herbicides. Oregon State University. Corvallis, Or. Feb 18-19. pp 25-28.

Kelpas, B., & Landgren, C. (2018). Forestry and Hybrid Cottonwoods In E. Peachy (Ed.), *Pacific Northwest Weed Management Handbook [online] https://pnwhandbooks.org/weed* Corvallis, Oregon: Oregon State University.

Ketchum, J.S. and R. Rose. 2000. Interaction of Initial Seedling Size, Fertilization and Vegetation Control. Proc. 21st Ann. For. Veg. Mgt. Conf. Jan 18-20. Redding, Ca. pp 63-69.

Knowe, S. A. 1992. Manual Techniques for Managing Woody Competition: An Overview. Proc. Forest Vegetation Management Without Herbicides. Oregon State University. pp. 90-91.

Kruger, W.C. and M. Vavra. 1984. 20th Year Results from a Plantation Grazing Study. Oregon Agricultural Experiment Station. Special Report 715: 20-24.

McDonald, P., G.O. Fiddler, R.A. Tucker and A. Colaninno. 1989. Manual Release in an Old Douglas-Fir Plantation Increases Diameter Growth. USDA Forest Service. Research Note. PSW-405. 3 P.

McDonald, P. and G.O. Fiddler. 1990. Ponderosa Pine Seedlings and Competing Vegetation: Ecology, Growth and Cost. USDA Forest Service. Research Paper. PSW-199. 10 P.

McDonald, P.M. and G.O. Fiddler. 1992. Mulching and Grubbing Techniques in Forest Vegetation Management: A Research Synthesis. Proceedings of a Workshop on Vegetation Management without Herbicides. Oregon State University. Corvallis, Or. Feb 18-19. pp 92-98.

McDonald, P. M. and G.O. Fiddler. 1993. Vegetative Trends in a Young Conifer Plantation After Ten Years of Grazing by Sheep. USDA Forest Service. Research Paper. PSW-RP-215. 9P.

McDonald, P. M., G.O. Fiddler and W.T. Henry. 1994. Large Mulches and Manual Release Enhance Growth of Ponderosa Pine Seedlings. New Forests. 8:169-178.

McDonald, P.M. and G.A. Everest. 1996. Response of Young Ponderosa Pines, Shrubs and Grasses to Two Release Treatments. USDA Forest Service. Pacific Southwest Research Station. Research Note. PSW-RN-419. 8 P.

McDonald, P.M. and C.S. Abbott. 1997. Vegetation Trends in a 31-Year-Old Ponderosa Pine Plantation: Effect of Different Shrub Densities. USDA Forest Service. Pacific Southwest Forest and Range Experiment Station. Research paper PSW-RP-231.

McDonald, P. and G.O. Fiddler. 1999. Recovery of Bear Clover (Chamaebatia foliolosa) Plant Community After Site Preparation and Planting of Ponderosa Pine Seedlings. USDA Forest Service. Research Note. PSW-RN-423. 7 P.

McDonald, P.M. and G.O. Fiddler. 2001. Timing and Duration of Release Treatments Affect Vegetation Development in a Young California White Fir Plantation. USDA Forest Service. Pacific Southwest Forest and Range Experiment Station. Research paper PSW-RP-246.

McDonald, P. and G.O. Fiddler. 2007. Development of Vegetation in a Young Ponderosa Pine Plantation: Effect of Treatment Duration and Time Since Disturbance. USDA Forest Service. Research Paper. PSW-RP-251. 23 P.

McHenry, W.B., A. Scarlett, T.F. Robson and L. Lindstrand Jr. 1982. Chemical and Mechanical Grass Control. Proc. 4th Ann. Forest Vegetation Management Conference. Eureka, Ca. pp.47-55.

Milliman, L.J. 1999. Effects of Sheep Grazing to Control Weeds in a Pine Plantation on Weed Reproductive Success, Trees and Sheep Performance. M.S. Thesis. Oregon State Univiersity. 82 P.

Moran, P.J. and S.M. Greenberg. 2006. Winter Cover Crops and Vinegar as Weed Control Techniques in Sustainable Cotton production. Proc. National Cotton Council Beltwide Cotton Conference. San Antonio, Tx. pp. 2188-2195.

Neary, D.G., P.B. Bush and J.E. Douglas. 1983. Off-site Movement of Hexazinone in Stormflow and Baseflow from Forest Watersheds. Weed Science. 31: 543-551.

Newton, M. and F.N. Dost. 1984. Biological and Physical Effects of Forest Vegetation Management. Final Report, Washington Department of Natural Resources. 423 P.

Newton, Michael and D.S. Preest. 1988. Growth and Water Relations of Douglas-Fir (Pseudotsuga menziezii) Seedlings Under Different Weed Control Regimes. Weed Science. 36: 653-662.

Newton, M. and E.C. Cole. 1993. Tall Planting Stock for Enhanced Growth and Domination of Brush in the Douglas-Fir Region. New Forests. 7:107-121.

Oester, P. T., W. Emmingham, P. Larson and S. Clements. 1995. Performance of Ponderosa Pine Seedlings Under Four Herbicide Regimes in Northeast Oregon. New Forests. 10:123-131.

Oliver, W.W. 1984. Brush Reduces Growth of Thinned Ponderosa Pine in Northern California. USDA Forest Service. Pacific Southwest Forest and Range Experiment Station. Research paper PSW-172.

O’Sullivan, P.A., J.T. O’Donovan, and W.M. Hamman. 1981. Influence of Non-ionic Surfactants, Ammonium Sulphate, Water Quality and Spray Volume on the Phytotoxicity of Glyphosate. Can. Jor. of Plant Sci. 61: 391-400.

Owen, M. D. 2002. Acetic Acid (Vinegar) for Weed Control Revisited. Extension Bulletin. Iowa State University. July 8, 2002.

Paley, S.M. and S.R. Radosevich. 1984. Effect of Physiological Status and Growth of Ponderosa Pine (Pinus ponderosa) and Greenleaf Manzanita (Arctostaphylos patula) on Herbicide Selectivity. Weed Sci. 32:395-402.

Pendl, F. and B. D’Anjou. 1990. Effect of Manual Treatment Timing on Red Alder Regrowth and Conifer Response. FRDA Report #112. B.C. Ministry of Forests. 14 P.

Peterson, T.D., M. Newton and S.M. Zedaker. 1988. Influence of Ceonothus Velutinus and Associated Forbs o the Water Stress and Stemwood Production of Douglas-Fir. For. Sci. 34(2): 333-343.

Pitcairn, Michael, J. 1999. Advancements in Biological Control of Weed Species Via Insects and Fungi. Proc. 20th Annual Forest Vegetation Management Conference, Redding, Ca. pp. 60-63.

Potter, D.A. 1984. Control of Bear Clover. Proc. 6th Ann. For. Veg. Mgt. Conf. Nov 1-2. Redding, Ca. pp 144-150.

Powell, R. L. 1992. Prescribed Fire for Conifer Regeneration in the Oregon Coast Range. Proc. Forest Vegetation Management without Herbicides. Oregon State University, Feb 18-19. pp.33-38.

Powers, R.F. and G.O. Fiddler. 1997. The North American Long-Term Soil Productivity Study: Progress Through the First Five Years. Proc. 18th Ann. For. Veg. Mgt. Conf. Jan 13-16. Redding, Ca. pp 88-102.

Powers, R. F. and P.E. Reynolds. 1999. Ten Year Responses of Ponderosa Pine Plantations to Repeated Vegetation and Nutrient Control Along an Environmental Gradient. Can. Jor. For. Res. 29: 1027-1038.

Radosevich, S.R., E.J. Ronconi, S.G. Conard, and W.B. McHenry. 1984. Seasonal Tolerance of Six Coniferous Species to Eight Foliage-Active Herbicides. Forest Science. 26:3-9.

Radosevich, S.R. 1984. Interference Between Greenleaf Manzanita (*Arctostaphylos patula*) and Ponderosa Pine (*Pinus ponderosa*). Seedling Physiology and Reforestation Success. Duryea, M.L. and Brown, G.N. editors. Martinus Nijhoff and Dr. W. Junk publishers. Boston. pp 259-270.

Rhodes, R.C. 1980. Studies with C14-Labeled Hexazinone in Water and Bluegill Sunfish. Agricultural and Food Chemistry. 28(2): 306.

Rose, R. and S.J. Ketchum. 2002. Interaction of Vegetation Control and Fertilization on Conifer Species Across the Pacific Northwest. Can. J. For. Res. 32:1-17.

Sharrow, S.H. 1992. Animal Grazing in Forest Vegetation Management: A Research Synthesis. Proc. Forest Vegetation Management Without Herbicides. Oregon State University. pp.53-60.

Simard, S. and J. Heineman. 1996. Nine Year Response of Douglas-Fir and the Mixed Hardwood-Shrub Complex to Chemical and Manual Release Treatments on an ICHmw2 Site Near Salmon Arm. FRDA Report #257. B.C. Ministry of Forests. 15 P.

Sparks, B.D., A. Sundaram, L. Kotlyar, J.W. Leung and R.D. Curry. 1988. Physiochemical Properties Deposition Pattern of Some Newtonian Spray Mixtures of Glyphosate Containing Two Spray Modifier Adjuvants. Jor. Env. Sci. Health. B23(3): 235-266.

South, D.B., J.L. Rakestraw and G.A. Lowerts. 2001. Early Gains from Planting Large Diameter Seedlings and Intensive Management are Additive for Loblolly Pine. New Forests. 22:97-110.

Steen, Ordell and A. Smith. 1991. Grass and Legume Seeding for Vegetation Control on Blade Scarified Sites in the ICH and ESSF Zones in the Central Interior of British Columbia. FRDA Report #182. B.C. Ministry of Forests. 23 P.

Stevens, P. J. G. and J. A. Zabkiewicz. 1990. New Formulation Technology-Silwet Organosilicone Surfactants have Physical and Physiological Properties which Enhance the Performance of Sprays. Proc. 9th Australian Weed Conference. Editor J.W. Heep. August 6-10. Adelaide Convention Center. Adelaide, South Australia. pp 327-331

Sundaram, A. 1990 (a). Effect of Nalcotrol 11 on Bioavailability of Glyphosate in Lab Trials. Jor. of Env. Sci. Health B 22(3): 319-346.

Sundaram, A. 1990 (b). Influence of Two Polymeric Adjuvants on Physical Properties, Droplet Spreading and Drying Rates, and Foliar Uptake and Translocation of Glyphosate in Vision Formulation. ASTMSTP 1086. American Society for Testing and Materials

Tappenier, J.C. and S.R. Radosvich. 1982. Effect of Bearmat (*Chamaibatia foliolosa*) on Soil Moisture and Ponderosa Pine (Pinus ponderosa) Growth. Weed Science 30:98-101.

Taylor, S.W., B.C. Hawkes, R.H. Silversides and M.G. Weber. 1991. Initial Effects of Prescribed Fire and Mechanical Site Preparation on Seedling Environment and Establishment on a Backlog NSR Site in Central Interior British Columbia. FRDA Report #177. B.C. Ministry of Forests. Canadian Forest Service. 29 P.

Thomas, D.F. 1983. The Use of Sheep to Control Competing Vegetation in Conifer Plantations. Proc. 5th Ann. Forest Vegetation Management Conference. Sacramento, Ca. pp. 138-142.

Timmer, V.R. 1997. Exponential Nutrient Loading: A New Fertilization Technique to Improve Seedling Performance on Competitive Sites. New Forests. 13: 279-299.

Wagner, R.G., and M.W. Rogozynski. 1994. Controlling Sprout Clumps of Bigleaf Maple with Herbicides and Manual Cutting. Western. Jor. App. For. 9(4): 118-124.

Wall, R.E. 1996. Pathogenicity of the Bioherbicide Fungus Chondrostereum purpureum to Some Trees and Shrubs of Southern Vancouver Island. Report. B.C. Ministry of Forests. Canadian Forest Service. 18 P.

Wall, R.E. and S.F. Shamoun. 1990. Experiments on Vegetation Control with Native Pathogenic Fungi in the Southern Interior of British Columbia. FRDA Report #134. B.C. Ministry of Forests. Canadian Forest Service. 17 P.

Weatherspoon, P. C. 1987. Prescribed Burning for Vegetation Management: Effects on *Ceonothus velutinus* Seeds in the Deff and Soil. Proc. 9th Ann. Forest Vegetation Management Conference. Redding, Ca. pp. 125-141.

Webster, J. and E.A. Fredrickson. 2005. Lessons Learned on 50,000 Acres of Plantation in Northern California. USDA Forest Service. Pacific Southwest Forest and Range Experiment Station. Gen. Tech. Rep. PSW-GTR-198

White, D. E. and M. Newton. 1989. Competitive Interactions of Whiteleaf Manzanita, Herbs, Douglas-Fir and Ponderosa Pine in Southwest Oregon. Can. J. For. Res. 19: 232-238.

White, D. E., L. Witherspoon-Joos and M. Newton. 1990. Herbaceous Weed Control in Conifer Plantations with Hexazinone and Nitrogen Fertilizations. New Forests. 4:97-105.

Whitehead, R. and G.J. Harper. 1998. A Comparison of Four Treatments for Weeding Engelmann Spruce Plantations in the Interior Cedar Hemlock Zone of British Columbia: Ten Years After Treatment. Information Report BC-X-379. Canadian Forest Service, Victoria British Columbia. 21 P.

Young, B.W., C.A. Hart and F.R. Hall. 1987. The Use of “Dial-a-Drop” Concept in the Study of Droplet Impaction with Leaf Surfaces. Aspects of App. Biol. 14:23-33

Chapter 8:
Forest Vegetation Management

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The Influence of Competing Vegetation in Forestry

The focus of this chapter is primarily on the use of chemicals to control competing vegetation both before and after the conifer seedlings are planted. Mechanical, fire, and managed intensive grazing approaches to controlling competing vegetation can also be used in combination with chemical methods or as a substitute method. These methods are typically more expensive per acre and often do not achieve the same level of control of competing vegetation.

Competition

The success of forest regeneration depends on many things. In California's Mediterranean climate, the most critical factor which influences the success or failure of establishing a new forest is competing vegetation (Powers 1999). Competing vegetation can and will deprive newly established conifer seedlings of valuable light, nutrients and most importantly, water (White & Newton 1989). In California, where summer temperatures can exceed one hundred degrees, relative humidity may be in the single digits and long periods without rainfall are common, competing vegetation in excess of just twenty five percent cover may be enough to influence growth and survival of first year seedlings (Oliver 1984).

Pioneer brush species and hardwoods inherently grow faster than conifer seedlings and can quickly over-top planted trees depriving them of valuable light needed for photosynthesis (McDonald & Abbott 1997). Herbaceous vegetation in the form of grasses and forbs has adapted to capitalize on early available soil moisture for growth, and can quickly deplete available water for seedlings (White, Witherspoon & Newton 1990). It is important to realize that any vegetation other than the planted conifers are utilizing light, nutrients and water that are required for successful establishment of new seedlings.

The impacts of competing vegetation on conifer seedlings have been well documented. Ponderosa pine (*Pinus ponderosa*) survival was dramatically increased by controlling bear clover (*Chamabatia foliolosa*). Tappeiner & Radosevich (1982) demonstrated that in areas where bear clover was not controlled, ponderosa pine survival ranged from six to twelve percent survival compared to eighty to one hundred percent where it was removed. The same study also predicted wood volume losses of 75 percent by age 50 if bear clover was not controlled. Fisk (1984) also estimated volume losses of up to 70 percent in mixed conifer forests where bear clover was not controlled. Oester et al. (1995) showed survival increased from 18 percent to 63 percent and stem volume increased from 39 cubic centimeters to 819 cubic centimeters in ponderosa pine five years after planting from a single application of hexazinone compared to untreated controls in northeastern Oregon. In a study by White & Newton (1989) ponderosa pine growth was substantially reduced by manzanita ground cover as low as 20 to 30 percent. Powers (1999) showed a threefold gain in stem volume averaged over all sites using herbicides compared to the non-treated controls eight years after treatment in the Garden of Eden Study. Ponderosa pine growth was reduced by 80 to 90 percent three years after planting when greenleaf manzanita cover reached 50 percent (Radosevich 1984).

Controlling competing vegetation is most important early in the life of a new forest. McDonald & Fiddler (2001) showed that delaying release treatments until four years after planting and then treating each year for the next three years did not significantly increase growth over the non-treated controls. Small trees that received release treatments during the first three years after planting were statistically larger McDonald & Fiddler (2001).

Fuel Loading and Fire Risk

A secondary reason to manage competing vegetation is to maintain a relatively fire resistant landscape. When woody brush goes unchecked, it can quickly outgrow planted conifers. Usually one or two species will dominate a site and suppress others. Heavy fuel loads accumulate and plant biodiversity is also reduced (DiTomaso et al. 1997). Radosevich (1984) showed that greenleaf manzanita (*Arctostaphylos patula*) biomass on a good site one year after planting was almost 60 times that of ponderosa pine seedlings. One year after planting a site that had been mechanically site prepped, greenleaf manzanita plant density consisted of 123,500 seedlings per acre. During the ten year study, manzanita plant numbers decreased, but foliar cover increased by 21 times while height increased by seven times (McDonald & Fiddler 2001). As the average investment by private landowners to establish new forests is around five hundred dollars per acre, managing the vegetation to reduce fire risk is critical. Fire proofing a stand is impossible, but by managing the density and size of vegetation the intensity of the fire may be lowered to allow survival of the stand.

Environmental Considerations

Herbaceous and woody vegetation do have positive benefits and are an important but minor component of most reforestation projects in California. They provide habitat and food for wildlife, protect water quality, increase soil stability and can provide some aesthetic qualities to the landscape. It is very important as a land manager to realize that effectively treating vegetation to establish a new forest produces a very short-term effect on the landscape. Vegetation rebounds very quickly and by not letting one or two species dominate a site, plant biodiversity and species richness increase in the long-term (DiTomaso et al. 1997). How one manages vegetation depends on the landowners objectives. Goals for wildlife, water quality, soils and aesthetics can be easily integrated into a management plan. The ability to recognize where, when and how special vegetation management considerations need to be addressed is critical to sound and responsible planning. Specific concerns will be addressed later in this text.

The chemical control of competing vegetation is tightly regulated in California and commercial application in limited to licensed professionals who must follow the latest regulations.

Choosing a Method of Vegetation Control

Choosing a method of vegetation control should not be taken lightly. Failure has significant ramifications that are enormous from both a financial and biological perspective. The inherent cost of treatment and the potential cost of failure should provide the incentive to choose wisely and do it right the first time. So what should be considered in choosing a method of vegetation control?

It is imperative that foresters fully understand the treatment objectives before starting. Site preparation treatments for conifer establishment are usually much more intensive than managing vegetation for wildlife or recreation to achieve the primary goal of fast growth of the desired set of newly planted trees. The land management objectives and constraints will dictate what methods are suitable and which are not. Land managers must have a clear understanding of the desired outcome in order to evaluate effectiveness of the components of their work.

The budget is a very important consideration. The greatest savings can be achieved by doing things right the first time. Vegetation treatments are inherently expensive. Some treatments cost much more than others and may be less effective. It is important to consider both present and future treatment costs. Are repeat treatments going to be necessary? Will the treatments be mechanical, chemical or manual?

Another question involves the duration of desired control. Manual and mechanical treatments generally provide short-term control, while certain herbicide prescriptions can provide control over a number of years. There are exceptions to the short term impacts of manual and mechanical treatments. Large whiteleaf manzanita (*Arctostaphylos viscida*) for example, re-sprouts very little when disturbed. If it is too large to treat chemically, mechanically piling or masticating may provide satisfactory control.

One of the most important things to be aware of when deciding on a treatment option is the surroundings. Are there any sensitive areas around that may preclude the forester from using one type of treatment over another? The presence of sensitive water courses or wells, property lines, neighbor issues, or endangered species are all things that may influence the decision on which type of treatment to use. The crop species tolerance to herbicides may be an issue that dictates using another method of control. For example, if a particular conifer species is intolerant to available herbicides, manual or mechanical removal may be a better option.

Worker safety may be an important issue that influences the selection of a method. Slope, rockiness, temperature and access may all be safety issues that favor one type of treatment over another. Newton &

Dost (1984) showed through medical records that the risk of worker injury was magnitudes greater with manual removal treatments when compared to hand applied chemical applications.

There is a wealth of knowledge available to landowners regarding all types of vegetation control depending on the resource professional. Generally, foresters that work for private industry, consulting foresters, pest control advisors, licensed applicators and university personal work more with chemical vegetation management than state or federal employees. State and Federal employees tend to rely more on non-chemical vegetation control than private and have a vast amount of experience with alternative treatments. County offices of the Department of Agriculture as well as the Department of Pesticide Regulation can also provide valuable information. Consulting with vegetation management professionals will save the landowner valuable time and money as well as ensure a successful application to achieve the desired objective.

Methods of Vegetation Control

There are many different methods for controlling unwanted vegetation, and the selection of the desired method is a keystone in the success of the reforestation project. These various methods are introduced here and may be found in greater detail later in this chapter or within other chapters of this book.

Chemical

Chemical vegetation control involves the use of herbicides, desiccants or growth regulators to control unwanted vegetation. The overwhelming majority of chemical vegetation management is done with herbicides and therefore will be the predominant method discussed in this text. Herbicides are generally the most effective and efficient method of vegetation control. Today's herbicides and application methods also have a very high margin of safety and any specific concerns can be easily mitigated (Newton & Dost 1984).

Mechanical

Mechanical vegetation control is done utilizing some type of equipment to manipulate existing vegetation on a site. Piling, ripping and mulching are common examples. With subsequent weed germination or resprouting, mechanical vegetation control alone does not provide control in the long-term (Fiddler & McDonald 1997). As a result, mechanical vegetation control is usually done in combination with other methods of vegetation control such as chemical. Mechanical treatments may be especially appropriate where large brush or trees that cannot be treated by other methods is present, or where some type of soil amelioration may be desired.

Manual

Manual vegetation control involves cutting, grubbing, pulling or some other method of physically removing vegetation by hand. Vegetation control using these methods is usually of short duration and application costs can be very high (Knowe 1992), and as a result, they are commonly used in combination with another method of vegetation control. Manual control of vegetation is particularly useful in areas that chemical application is not feasible, such as projects in close proximity to residential areas or in areas that may be sensitive to herbicide application due to multiple water courses and associated buffer zones. Other uses might be in very remote areas with limited access by application equipment where grubbing crews can provide a release treatment by hiking into the treatment site. Manual treatments are frequently used by the United States Forest Service (USFS) in their reforestation activities, at least, in part, due to the complex authorization process required prior to use of chemical treatments.

Biological

Biological control is achieved utilizing a naturally occurring organism or substance to control vegetation. Successful examples of biological control include control of tansy ragwort (*Senecio jacobaea*) using the Cinnabar Moth (Fuller 2002) and control of St Johnswort (*Hypericum perforatum*) with the Klamath weed beetle (Holloway 1964). Pathogenic fungi are also under investigation to control certain types of vegetation, but to date the results have not been as successful (Wall 1996, Wall & Shamoun 1990). Biological control methods are usually limited to very specific pests, which does not make them applicable to broad spectrum vegetation control. They are usually also restricted to certain geographic ranges or elevations. In most cases, biological controls are a small part of a larger management program (Newton & Dost 1984).

Cultural

Cultural treatments are management practices that have a direct or indirect effect on vegetation control and can take on many forms. They can be land management activities such as burning or grazing that can affect competing vegetation itself, or seedling development programs such as seedling nutrition or stock type selection to enable seedlings to outcompete the vegetation. There is virtually an endless stream of concepts and ideas that one can incorporate into a management program to try and minimize vegetation management inputs. Like some of the other methods of vegetation control, cultural treatments are only a part of an integrated approach for vegetation management.

Non Chemical Weed Control Methods

Mechanical Weed Control

Mechanical operations in forestry are not always solely for the purpose of weed management. Mechanical treatments may have multiple objectives included mitigating compaction, improving water absorption, facilitating planting, slash removal, thinning or vegetation management. Mechanical treatments are also not usually used alone, but are one part of a larger program (McHenry 1982).

The majority of the discussion of mechanical site preparation treatments as they refer to aspects other than vegetation will be discussed in the site preparation chapter of this manual. We will briefly discuss the benefits associated with vegetation removal here. Mechanical vegetation removal can be an important part of the reforestation program and will usually have a significant impact on future treatments regarding cost, quality and accessibility.

Biomass removal

Removal of unwanted vegetation may start before the logging operations are even completed. When markets allow, one of the most important mechanical treatments foresters can do is biomass removal or chipping. The ability to chip unwanted material in the woods has several advantages. Fuel loading is drastically reduced as unwanted material is chipped and hauled off site. The costs of piling and potentially slashing after logging are drastically reduced or not needed at all. Poor quality sub-merchantable conifers can be easily and efficiently removed. Accessibility for planters, spray crews, and other reforestation efforts is improved. While the chipping treatments won't provide long-term control of the competing vegetation that is removed, it does bring it down to a manageable level. Future entries for chemical, hand or mechanical treatments will be much easier and more cost effective.

Piling

Depending on the slash load and component of large woody brush or sub-merchantable conifers following logging operations, reforestation units may need to be piled to improve access, remove residual vegetation and facilitate planting operations. Weed control by piling is primarily through the removal of large brush. In many cases, large plants such as manzanita can be entirely pulled or pushed from the ground root systems and all. This can control some plants where the entire plant system can be removed. In other cases the brush is too small or flimsy to be entirely removed and control must rely on some other method. If pre-sprayed prior to harvesting, much of the brush is dead by the time piling occurs, and it can be easily crushed or piled. This also reduces the amount of time needed for piles to dry in preparation for burning.

Piling operations can be conducted with several different types of equipment. Bull dozers are the primary method used. All bull dozers utilized for piling should be equipped with brush rakes to minimize the amount of soil disturbance.

Excavator piling is another option that has several additional benefits. Much less of the ground is covered by the tracks of an excavator compared to a bull dozer due to the reach of the boom, and as a result, potential compaction is lessened. Using the grapple of the boom, large brush and woody sprout can be pulled from the ground minimizing movement of topsoil. Furthermore, steeper slopes can also be reached with an excavator, often times up to 40 percent.

Piling costs when using tractors in logging units usually range between $150 and $250 per acre for logging units, but the use of excavators is more expensive and can add another $50 to $100 to the per acre cost. If converting old brushfields, piling costs are usually higher when dense and large old brush is present that must be removed prior to any other activity. It has become less popular to utilize piling for site preparation. Increased opportunities are now available to avoid the cost and disruption of piling. These include chemical pretreatment and planting through resultant slash and creating micro-sites for conifer seedlings with equipment that does not operate over the entire unit's surface area. In addition, poor piling practices can impact site quality through excessive soil disturbance. Finally, the liability when burning piles or windrows created by this method is a risk many landowners are now unwilling to accept.

Sub-soiling

Site preparation treatments with sub-soiling utilize a bulldozer fitted with a brush rake and a series of steal shanks fitted with slightly angled wings on each side of the shank. The shank and wings are designed to rip, lift and drop the soil to mitigate compaction. A secondary result of the treatment is that it disturbs any remaining vegetation it comes in contact with.

One of the largest environmental studies in the history of the United States is the Long Term Soil Productivity Study (LTSP) which is installed on many sites across the country (Powers & Fiddler 1997), with twelve sites installed in California. The study looked at several factors affecting conifer survival and growth including compaction, vegetation management and soil organic matter. Treatments consisted of light, moderate and heavy compaction, with or without vegetation, and organic matter removed or present. The LTSP study has been in existence since 1989 and occurs over a wide range of conditions and soil types across the country.

Regarding the sub-soiling effect on vegetation, the results vary by site but on the Challenge, California site some interesting results occurred. At the end of the fourth growing season the average ponderosa pine volume increment was greatest in the compacted plots and least in the lightly compacted treatments that were sub-soiled in two directions. This seems counter intuitive, but it is because of the competing vegetation this occurred. Vegetative cover averaged 56 percent in the compacted plots and 91 percent in the sub-soiled plots. Less weed cover translates to increase moisture availability. When the effect of vegetation was removed, the sub-soiled plots were clearly superior to the compacted ones (Powers 1997). Potter (1984) also showed that when units with bear clover present were ripped, rhizomes were broken up and spread across the unit resulting in even more of an infestation. This result seems to heavily rely on the type of vegetation present. Others have shown very positive growth responses on ponderosa pine to sub-soiling (Helms et al. 1986, Froehlich & Robbins 1983).

Mastication

Mastication involves crushing or grinding vegetation on site with some type of specialized head mounted on a piece of heavy equipment. This method of vegetation control is expensive, but negates the need to follow-up piling. Organic mulch that is left on site may also increase the water holding capacity of the soil (Hudson 1994). It is a good method to use when vegetation is large enough to hinder reforestation efforts and can sometimes be used in place of broadcast burning. Masticating the vegetation will not kill re-sprouting species, and as result, it is best used in combination with herbicides for effective control. Recently, dense stands of 60 year old tanoak regrowth in the Sierras have been operationally treated using this method. Trees were severed and laid on the ground with a feller buncher and then masticated. This created a relatively thick layer of shredded organic matter that could be picked through for planting spots, albeit with some difficulty. While this operation was expensive, ranging from $400 to $500 per acre, it created an opportunity for recapturing hardwood-dominated, high site timberland that would otherwise have required heavy equipment clearing and high risk burning, if even possible at all. As mentioned earlier, the resultant fuel loading during the early years of the plantation must be considered, and the presence of re-sprouting species would require the consideration of a site preparation spray as part of the prescription.

One masticating site preparation tool that has been used in the past, but now with relatively limited availability, is the VH Mulcher. This machine utilizes a high-torque spinning head with angled blades that is ground down into the soil. In so doing, it not only masticates vegetation in a circular area about four feet in diameter, but also alleviates surface compaction and creates planting spots for seedlings. It is expensive and can run between $250 and $400 per acre depending on the number of planting spots created, density and size of brush, slope and rockiness. This method generally does not preclude the need for herbicide treatment of the surrounding terrain, as encroachment from the edges can be fairly rapid. Care should be taken in some soil textures as the vigorously disturbed planting spots may initially have a high percentage of macro pores that can impact root growth.

Using masticating heads on a maneuverable boom can reduce residual damage to the conifer plantation. Where large brush is present in established plantations, mastication can be used as an effective release tool by reducing brush competition at the same time as pre-commercially thinning existing conifers to desired levels. Release treatments such as these usually occur in older plantations, where brush has been allowed to dominate and is too large for any type of manual treatment.

Fiddler and McDonald (1997) compared different mechanical release treatments in a 12 year old Ponderosa pine plantation which included a non-treated control, removing vegetation with a Hydro-Ax shear only, and removing vegetation with the shear followed by an application of 2,4-D to the re-sprouting vegetation the year after masticating. After 11 years, the Hydro-Ax plus the use of herbicide had significantly larger crowns, diameter and height than either the Hydro-Ax alone or the non-treated controls. The only difference between the hydro ax only treatment and the untreated controls was in crown volume. A study by Fiddler et al. (2000) showed similar results on a 16 year old ponderosa pine plantation using a Trac-Mac shear instead of a Hydro-Ax. The treatments consisted of a untreated control, Trac-Mac cut-only, and Trac-Mac cut plus a herbicide treatment with 2,4-D two years after cutting. Eleven years after treatment the Trac-Mac only treatments had no significant differences in crown volume, diameter or height compared to the non-treated controls, whereas the Trac-Mac plus 2,4-D treatment had significantly larger crowns than the untreated control or the Trac-Mac only treatment. Somewhat larger diameters and heights resulted from the Trac-Mac plus 2,4-D treatment, and while not significant, the authors did point out that growth rates were diverging over time between treatments.

All mechanical mastication methods are expensive and should be reserved for those situations where other options are limited or specific objectives have been identified, such as reduction of herbicide use or elimination of burning. When needed for release, the costs necessary to reclaim a site using mechanical methods emphasize the importance of adequate vegetative control in the first place.

Manual Weed Control Methods

An advantage of manual weed control is that these methods can be more socially acceptable and have fewer environmental constraints than other methods. Additionally, manual treatments can be highly selective and can even be incorporated into pre-commercial thinning programs. The disadvantages of manual treatments is that they require a large skilled crew, often result in more worker injuries, and are less effective than chemical methods (Newton & Dost 1984). The largest disadvantage is high cost and a very short duration of control (Knowe 1992).

Manual release treatments can include such treatments as hand grubbing, cutting, utilizing mulch mats, shade cards and other non-chemical control methods. Probably the most popular method of manual weed control is hand grubbing. Hand grubbing involves the manual removal of live vegetation through the use of hoes, shovels or other implements. Hand grubbing is usually done after the seedlings have been planted. To maximize effectiveness, treatments should occur after the large majority of vegetation has emerged in the late spring to early summer and should remove all root systems within the grubbed area to be effective.

Several studies have evaluated the results of hand grubbing. McDonald and Fiddler (1990) compared several sizes and intensities of hand grubbing treatments to a single application of Velpar L (hexazinone). Treatments included two and four foot scalps applied at age one, half of which were expanded to four and six foot scalps at age four. Four years after treatment, trees treated with the single application of Velpar L were significantly larger in caliper and height for all treatments except the four foot scalp that was expanded to six feet. No grubbing treatments had significantly larger calipers or heights than the non-treated controls other than the six foot radius scalp. Labor costs were high, however, with the six foot radius scalp treatment costing $578 per acre in 1984 dollars compared to $38 per acre for the single Velpar L treatment. With annually repeated grubbing treatments for the first three years after planting, McDonald and Fiddler (2007) did show increases in caliper and ponderosa pine leaf area compared to non-treated controls, but at a cost of $1890 per acre assuming labor rates of $28 per man hour.

While expensive, hand grubbing can be successful in achieving survival provided the scalps are large enough and the treatments are repeated when competing vegetation returns. In the absence of chemical vegetation control methods, the hand grubbing treatment is better than doing nothing.

Cutting brush or hardwoods with a chainsaw or hand saw is another manual method to release conifer seedlings. However, doing so without chemical follow up is a very short-term treatment. McDonald et al. (1989), showed that tanoak cut with a chainsaw was over-topping Douglas-fir seedlings four years after treatment. By nine years after treatment, Douglas-fir height was not significantly different from the non-treated controls, and only small gains in Douglas-fir diameter were achieved. D'Anjou (1990) found that when woody brush and hardwoods were cut, they reached 50 percent of their pre-treatment height by the end of the first growing season. The study also showed no brush mortality occurred as a result of cutting and timing of treatment had little effect. When compared to herbicide treatments, cutting provided significantly poorer control than glyphosate. Similar results were found by Simard and Heineman (1996), who showed that cutting had no effect on Douglas-fir caliper or height nine years after treatment, but treatments with glyphosate significantly increased diameter. The same study on a different site showed significantly larger diameters on lodgepole pine for the cutting and glyphosate treatment compared to non-treated controls nine years after treatment. Whitehead and Harper (1998), compared four types of vegetation control for release of Engelmann spruce including treatments with glyphosate, 2,4-D, manual cutting and a non-treated control. Ten years after treatment, the glyphosate treatments were the most effective in reducing brush cover and height and significantly reduced the height to diameter ratio and competition index. All other treatments failed to meet Canada's minimum stocking standards at the completion of the study. Mixed results on conifer growth have been found by others. Pendl and D'Anjou (1990) found no growth response from grand fir but height growth in Douglas-fir was significantly increased five years after cutting.

If cutting is to be done, some of the literature suggests it is better to cut woody brush and hardwoods later in the season when carbohydrate reserves are low (Pendl & D'Anjou 1990). Increasing the frequency of cutting and cutting to the lowest stump heights possible may also reduce the amount of re-sprouting (Harrington & Tesch 1992), and cutting is much more effective when followed up with herbicides to reduce sprouting (Wagner & Rogozynski 1994). McDonald & Tucker (1989) concluded that cutting treatments are very expensive for a short-term reduction in cover.

Another manual method that has been used over the years is the use of mulch mats. Mulch mats can be made out of paper, plastic, polyester, asphalt or other durable material and range in size up to ten feet in diameter. The purpose of placing mulch mats around tree seedlings is to deprive competing vegetation of light, heat the soil enough to prevent germination and retain valuable soil moisture for tree seedlings (Haywood 1999). Mulch mats can be an effective method of control in certain instances but they are expensive, difficult to install, require maintenance to maintain their position around seedlings, are problematic with sprouting species and often don't degrade in a reasonable amount of time (McDonald & Fiddler 1992).

Early polyester mulch mats reduced the amount of vegetation around tree seedlings, but didn't significantly increase Douglas-fir diameter or height over the controls (McDonald & Fiddler 1992). It found that the mats didn't allow water to penetrate, creating desert like conditions for seedlings. As a result, the type of material used is extremely important, and subsequent studies found that Pac-Weave was the best available material that didn't constrict tree growth, reduce water penetration, degrade too fast and was easy to install (McDonald & Fiddler 1992, Craig & McHenry 1987).

Conifer growth responses from the use of mulch mats are mixed. McDonald et al. (1994), compared polyester and paper mulch mats to hand grubbing treatments annually repeated for five years. Five years after treatment on Ponderosa pine seedlings, the polyester mats and the hand grubbing treatments yielded significantly larger diameter and heights compared to non-treated controls. However, the cost of the mulch mats was $2072 per acre. Harper et al. (2005) found that mulch mats reduced the amount of herbaceous vegetation in the first three years, but they failed to significantly increase survival, diameter or height for Douglas-fir seedlings compared to non-treated controls. That is the opposite of treatments with either glyphosate or hexazinone in that study. Haywood (2000), found that both mulch and hexazinone treatments resulted intaller loblolly pine seedlings and caused them to grow out of the grass stage faster than the non-treated controls. Other studies by Haywood (1999) had mixed results regarding growth of loblolly pine.

Mulch mats may have some potential, but are expensive and require considerable labor to install. McDonald and Fiddler (1992) reported the cost of large mulch mats can be as high as $9.90 per seedling, severely limiting the number of seedlings that can be treated effectively. Land managers that choose to use mulch mats may just want to focus on treating only a certain number of crop trees to keep the costs down.

Manual vegetation control treatments will always have some fit in forest management. However, when used alone, results will be extremely short-term and are best used in combination with chemical treatments for lasting control. If chemical methods are not available, it is important to realize that repeated manual treatments will be necessary and costs will be high.

Biological Control Methods

Biological control of vegetation can be attempted by several different methods. Insects, pathogenic fungi and the use of allelopathic organisms are all methods of biological control. Very little is known about the latter two methods, but some gains have been achieved with the use of insects on species such as Klamath weed (St Johnswort), tansy ragwort and to a much lesser degree Mediterranean sage. (Fuller 2002, Isaacson & Brookes 1999). Currently, new biological agents are being tested for control of alligator weed, Cape ivy, Dalmation toadflax, gorse, musk thistle, Russian knapweed, Russian thistle, Scotch broom, tamarisk and yellow star thistle. Of these, the hairy weevil which was introduced to California to control yellow star thistle is showing the most promise, but yellow star thistle populations remain high.

The problem associated with biological control agents is that they are usually very host specific. From a forester’s standpoint, controlling one weed out of a thousand does little to reduce competition. Getting populations of insects established is another concern. In many cases predators reduce populations of beneficial insects to insignificant levels. Some insects only produce one generation per year making establishment difficult (Pitcairn 1999). Using biological control agents is usually out of the forester’s control as these programs are usually designed and implemented by the state. There is definitely some potential benefit from biological control, but using insects should be one small part of a larger vegetation management program (Newton & Dost 1984).

Cultural Weed Control Methods

Cultural methods of weed control are indirect management techniques that increase a conifer seedlings ability to out-compete the vegetation. Many types of activities could be considered cultural treatments and more often than not foresters may not even realize they are practicing cultural vegetation management. Regarding this text, we will try and focus on a few of the more relevant concepts.

The Seedling

One of the more obvious cultural treatments a forester can manage is that of producing the conifer seedling itself. Any variable that the forester can manipulate in the nursery to give the conifer seedling a competitive advantage over the vegetation in the field is a cultural treatment. Stock size is the first factor that comes to mind, but different stock sizes behave differently depending on the geography. In wetter high site climates, several authors have shown larger stock sizes for Douglas-fir to increase growth and survival (Ketchum & Rose 2000, Newton et al. 1993). Other authors have shown the stock size effect to be an additive effect when combined with vegetation management and fertilization (South et al. 2001). In drier Mediterranean climates however, Fredrickson (2005) showed that growth differences due to initial stock size were short lived and varied by species. All initial differences in size had disappeared by year 5.

One of the most important seedling variables to manage in the nursery for drier climates, is the shoot to root ratio. Seedlings will compete better with vegetation in the field if they have a balanced shoot to root ratio. Large tops and small root systems cause the seedling to transpire faster than the root system can acquire water for the seedling, resulting in growth loss or death. The nursery manager can manage seedling heights and the shoot to root ratio by regulating photoperiods, thereby tricking the tree into thinking the day length is getting short. This causes the tree to set bud and harden off earlier.

Seedling Nutrition

Seedling nutrition is another critical factor that can give seedlings an initial advantage over the competing vegetation. Timmer (1997) has shown that exponential nutrient loading of seedlings in the nursery can induce a steady state buildup of nutrient reserves in seedlings for out-planting. He has consistently shown greater growth and increased nutrient uptake after out-planting compared to conventionally fertilized seedlings of the same stock size. Powers (1999), has shown the benefit of nutritional amendments in the field to ponderosa pine growth, but only in combination with weed control. If weeds were not controlled, any nutrients added to the site were taken up by the competing vegetation and any potential gains to conifers were lost. Powers also noted that fertilization success in the field also depended on moisture availability and water holding capacity. Others have shown water to be a limiting factor regarding fertilization response in the field (Rose & Ketchum, 2002).

The idea of incorporating slow release fertilizer in with the soil media in the nursery initially showed increased growth responses in the field with ponderosa pine (Fan et al. 2002). However, when operational testing and planting was conducted in California, severe root mortality occurred from salinity build up in the plug media, especially during storage. These problems are exacerbated in hot and dry climates where flushing of the root system from spring rains is sparse. This method of fertilization is not recommended for dry California climates.

Grazing

Grazing is a cultural treatment that has been practiced for centuries. Grazing practices in forestry have been done primarily with ungulates such as cattle, sheep and goats. They are usually effective in reducing the amount of herbaceous and woody brush cover depending on the species present (Sharrow 1992, Fullmer 1986, Krueger & Vavra 1984, Thomas 1983). Reductions in vegetative cover however, are short-term and eventually recover (McDonald & Fiddler 1993). Grazing has also released non-palatable vegetation that has actually increased in percent cover after grazing (Fullmer 1986).

The reduction in vegetative cover does not necessarily mean an increase in conifer growth or survival. Results are mixed in the literature as to the benefits regarding seedling growth and survival. In many cases, no beneficial effect of grazing was seen (Milliman 1999, McDonald & Fiddler 1993), while others have documented increases (Barolome 1989, Krueger & Vavra 1984).

Timing and grazing intensity play a significant part in damage to crop trees. Milliman (1999) reported that browse damage on conifer seedlings was the greatest with the highest intensity of grazing pressure and in June when the early season forage was maturing but before the late season forage had begun to grow. Fullmer (1986), also reported that sheep had browsed 49 percent of ponderosa pine and sugar pine buds at one site when browsing occurred prior to conifer bud set in the summer. Grazing was delayed on a second site until after bud set and browsing conifer buds was reduced to 10 percent.

To manage grazing effectively it is somewhat labor intensive. Fences need to be constructed, maintained and moved as needed. Herds need to be rotated to insure over grazing does not occur. Water can also be an issue if not present on site.

Fire

One of the most common cultural treatments historically used to manage vegetation in forestry is fire. Today with increasing constraints and regulations regarding air quality and smoke management along with general liability concerns, this practice is used much less frequently. Historical uses of fire revolved around reducing post-logging slash and residual vegetation on site. The largest advantage of fire is on steep slopes where heavy equipment cannot be used. The use of fire subsequently reduces difficulty for hand crews when planting, spraying and thinning, thereby, reducing costs (Newton & Dost 1984). Substantial gains in vegetation control have also been shown when burning is used in combination with herbicides (Powell 1992). Burning without the use of herbicides can actually release some fire adapted species such as deerbrush, snowbrush, blue blossum (*Ceanothus thyrsiflorus)* and knobcone pine (*Pinus attenuata*) (Weatherspoon 1987, Newton & Dost 1984).

Fire has been shown to increase conifer survival and growth, especially in combination with herbicides (Taylor et al. (1991). The authors looked at piling, broadcast burning and spraying, burning alone, and all treatments with and without disking. Two years after treatment, the spray plus burning treatment had greater consumption of fuel compared to burning alone, and better vegetation control and seedling growth than either burning alone or the piling treatment.

Under burning is also a valuable tool to clear away under story slash, vegetation and smaller unwanted sub-merchantable conifers. Arno et al. (1996) and Newton & Dost (1984)) noted the importance of thinning in combination with fire, along with utilizing other vegetation management options including herbicides to maximize effectiveness. Burning should not be looked upon for fuels reduction as the sole option. Reducing fuels or creating fuel breaks without maintaining them is a waste of time and money. Vegetation will come back rapidly after fire and needs to be managed to prevent an even greater buildup of fuels (Newton & Dost 1984).

There are several disadvantages to using fire for vegetation management. The liability associated with burning is significant as there is always the risk of escape and associated suppression costs. The importance of developing and following a detailed prescription for any planned fire is essential. The forester must also have the experience and ability to call off a potentially high risk burn when conditions are not right. Cutting, clearing and walking fire-lines on steep slopes can also be dangerous, although, Kauffman (1992) demonstrated that the incidence of worker injury and workers compensation claims during post burning activities such as planting, backpack spraying and thinning was less on units that had been broadcast burned compared to units with heavy slash and brush loads.

Chemical Weed Control

As noted in Forests and Right-of-Way Pest Control (Dreistadt 2013) published by UC Agriculture and Natural Resources, herbicides are the most used pesticides in forests because of their effectiveness in controlling competing vegetation. In the most recent edition of the Pacific Northwest Weed Management Handbook, it was noted that reforestation success depends heavily on weed control and that “In the past 20 years, research has made clear that virtually no other practice will produce as much gain in plantation performance as reducing competing cover, and that careful application of the appropriate chemicals exceeds other methods in safety, cost and habitat protection for most operations." (Kelpas and Landgren 2018). The use of chemicals for weed control in California forestry settings are highly regulated by both the US Environmental Protection Agency and the California Department of Pesticide Regulation. Table 8.1 summarizes the herbicides used in forestry by their active ingredient, type of activity and uses.

Table 8.1 Properties and uses of herbicides registered for forestry use in California. Herbicides noted for directed release means there is no over the top conifer tolerance.

Active Ingredient	Type of Activity	Uses
2,4-D ester	foliar	site prep/directed release
aminopyralid	foliar and soil	site prep/directed release
atrazine	soil	site prep/release
clopyralid	foliar and soil	site prep/release
fluroxypyr	foliar	site prep/directed release
glyphosate	foliar	site prep/release
hexazinone	soil	site prep/release
imazapyr	foliar and soil	site prep
oxyfluorfen	soil	site prep/release
penoxsulam	soil	site prep/release
sulfometuron-methyl	soil	site prep/release - coast only
triclopyr ester	foliar	site prep/directed release

The following sections descried the types of herbicide used in reforestation, resource and applicator protection measures, and logistical issues of application.

Types of Herbicides in Forestry

There are several types of herbicides that are currently used in forestry including growth regulators, ALS inhibitors, photosynthesis inhibitors, protoporhyrinogen oxidase inhibitors (PPO inhibitors) and the newest mode of action, cellulose biosynthase inhibitors. Each controls plants in its own way.

Growth Regulators

Growth regulators used in forestry include triclopyr, 2,4-D, aminopyralid, clopyralid and fluroxypyr. Growth regulators control plants by causing rapid cell wall expansion and collapse. Typical symptoms of growth regulator herbicides include twisting and curling of foliage, stems and roots. Growth regulators come in both ester and amine formulations. Typically it's the oil soluble ester formulations that are used in forestry due to superior weed control and better penetration into leaf surfaces over the water soluble amine formulations. However, use of esters is typically limited to the spring and fall due to volatility issues during the hot summer temperatures. The amine formulations are non-volatile, and fluroxypyr ester is much less volatile than 2,4-D or triclopyr ester.

Growth regulators are primarily used to control woody brush and herbaceous broadleaves (triclopyr, fluroxypyr and 2,4-D). Aminopyralid and clopyralid only have activity on herbaceous broadleaves and some annual grasses, but have both foliar and soil activity. Conifer tolerance with triclopyr and 2,4-D is high when applied as a pre-plant application since there is no soil activity. Neither can be used over the top of conifers in California. Aminopyralid also can not be applied over the top of conifers, but has some conifer tolerance when applied as a pre-plant. Clopyralid has excellent conifer tolerance applied pre or post plant over the top of seedlings. Trees can occasionally be injured from soil uptake as a pre-plant treatment, but if damage occurs at all the trees usually recover in a short amount of time.

Aceto-Lactase-Synthase (ALS) Inhibitors

ALS inhibitors inhibit formation of the enzyme aceto-lactase-synthase in plants that is necessary for the formation of essential aromatic or aliphatic amino acids in plants. These amino acids are only found in plants. These herbicides tend to be highly systemic and travel readily through plant tissues. Examples of ALS inhibitors in forestry include glyphosate, imazapyr and sulfometuron methyl. ALS inhibitors mainly occur as water soluble amines. Ester formulations do not exist and volatility is not an issue.

ALS inhibitors can have foliar and soil activity. Glyphosate is strictly foliar active, imazapyr has both strong foliar and soil activity and sulfometuron methyl is strictly soil active. The three have a mixed range of conifer tolerance as well. Glyphosate may be applied over the top of seedlings that have been established for one year after bud set in the late summer or as a pre-plant application. Applications made over the top of seedlings during the active growing season will cause significant damage or mortality. Release applications with imazapyr in California with a few exceptions are not possible due to very low conifer tolerance both from foliar and soil uptake. Even pre-plant site preparation treatments the year prior to planting may see significant conifer injury from soil uptake. Imazapyr has mainly found a fit in forestry applications in California as a pre-harvest treatment prior to logging that will be discussed further in this text. Sulfometuron methyl may be applied as a pre or post plant application on the Coast over redwood seedlings in California, but in the interior parts of the state with a drier climate, significant root suppression, top stunting, or even mortality occurs in conifers. This is mainly due to the inhibition of root growth and as a result, seedlings are not able to capture available soil moisture.

Photosynthesis Inhibitors

The triazine herbicides which include hexazinone and atrazine control plants by inhibiting the Hill reaction which in turn inhibits photosynthesis. Both hexazinone and atrazine are soil active herbicides which are absorbed by plant roots and require rainfall to activate. Atrazine is primarily a pre-emergent herbicide. Once grass and herbaceous broadleaves grow to over three or four inches tall, efficacy is reduced. Hexazinone is a more powerful herbicide and can be applied as a pre or post emergent herbicide, and has some activity on woody brush, which atrazine does not. Conifer tolerance with atrazine is excellent. Applications can be made pre or post plant to any of the conifers native to california. Hexazinone on the other hand has very good tolerance on ponderosa pine, but moderate to no tolerance on other conifers native to California.

Protoporphyrinogen Oxidase Inhibitors (PPO) Inhibitors

PPO inhibition is a new mode of action to California forestry. PPO inhibitors prevent plants from making the enzyme protoporphyrinogen oxidase which results in the destruction of cell membranes. They kill through lipid peroxidation, which is the process in which free radicals take electrons from the lipids in cell membranes causing the destruction of the membrane. The only PPO inhibitor currently registered in California is a component of Dow Agrosciences' product Cleantraxx. Cleantraxx is a combination of two different active ingredients and two different modes of action. The product contains the active ingredients oxyfluorfen, a PPO inhibitor, and penoxsulam which is an ALS inhibitor. ALS inhibitors have already been explained.

The two active ingredients work well together. Oxyfluorfen and penoxsulam have both soil and foliar activity. Oxyfluorfen controls herbaceous broadleaves and annual grasses only. Penoxsulam is a relatively new active ingredient and the list of plants controlled is still being determined, but it appears to have some activity on herbaceous broad leaved plants and weaker activity on woody brush. It does however, inhibit the germination of several woody brush species from seed. The product works best as a pre-emergent application, but does have some selective knockdown of existing vegetation as a post-emergent application. Conifer tolerance is excellent as a pre or post emergent application on all conifers tested in the northwest.

Cellulose Biosynthase Inhibitors (CBI's)

A recently new mode of action is about to enter into the forestry market as the active ingredient indaziflam. Indaziflam is a cellulose biosynthase inhibitor. It controls plants by inhibiting cellulose synthesis, inhibiting germination and root development. Indaziflam is primarily soil active, but does have minor foliar activity. The best fit with indaziflam is with pre-emergent applications. If vegetation is already existing on site, another product must be added to achieve knock down.

It mainly controls annual grasses and herbaceous broad leaved plants. It does not have any activity on woody brush at all. Conifer tolerance is very high, even on western larch, sugar pine and redwood seedlings which are the most herbicide intolerant conifers in the western United States. Conifer safety is maximized with pre-plant applications. No products with indaziflam are currently registered for forestry use in California.

Differences Between Soil and Foliar Active Herbicides

There are several differences foresters should be aware of regarding the mechanism of uptake that a herbicide has. Soil active products are taken up by the roots and require rain to activate. Foliar active products are taken up through the leaves and in some cases stem tissue. Products with soil activity tend to have longer residual control because they are more persistent and have longer half lives in the environment than foliar active products. Some soil active herbicides like hexazinone tend to be very mobile in the soil whereas, others such as atrazine and oxyfluorfen are much less so. Foliar active herbicides are generally not mobile in the soil. It is possible for a herbicide to have both foliar and soil activity, such as imazapyr which has very strong activity for both.

Soil active herbicides are heavily influenced by soil type, texture and percent organic matter. Those that have a high affinity to adsorb to soil particles are less available for plants to uptake and can negatively affect control. Adsorption to soil particles is measured by the soil adsorption coefficient, or Koc. The higher the Koc, the more that soil adsorbs to soil particles and the less mobile it may be in the environment. This measurement in combination with the solubility (S) of the herbicide can give some indication of the potential mobility of a herbicide in the environment. Highly soluble herbicides are generally more mobile. However, mobility in the environment is heavily influenced by the forest soil. Herbicides in clays or clay loams are generally less mobile than in loamy sands or sands (Dreistadt 2013), as they are in high organic matter soils. Several of the soil active herbicides such as hexazinone strongly adsorb to organic matter hindering plant uptake (Neary, Bush & Douglas 1983). Just because a herbicide has a high Koc or solubility doesn't necessarily mean that it is going to be mobile on any given soil. Results are highly variable in the field. In addition, slope also can have a major influence on mobility.

Non-Synthetic Herbicides

A brief mention will be given to what is referred to as non-synthetic herbicides. These are naturally occurring materials occasionally used for weed control, mostly in organic agricultural programs. They include such compounds as acetic acid (vinegar), citric acid, clove oil, cinnamon oil and corn gluten meal. These compounds are desiccants that accelerate the drying of plant tissue. The herbicidal symptoms they produce are limited to desiccating above ground plant tissue. They do not control the root systems of plants or translocate as true herbicides do.

These material have in some cases controlled very small, freshly germinated herbaceous seedlings. They will not control brush or mature herbaceous vegetation adequately. Plants not killed by these treatments recover rapidly after initial symptoms appear (Chandran 2009, Evans & Bellinder 2009, Moran & Greenberg 2006, Chase et al. 2004, Brevis et al. 2004, Corran et al. 2005, Owen 2002). These types of treatments are completely inadequate for forestry use. It should also be noted that in California, these materials are considered herbicides and need to be registered for use as such by the California Department of Pesticide Regulation. Acetic acid is not on the 25b exempt list of California or the U.S. EPA. However, the other active ingredients such as citric acid, clove and cinnamon oil and corn gluten meal are exempt and do not require registration (unless exceeding concentrations of 8.5% in California). They are considered pesticides in that a licensed pest control business is required to apply them in California but are exempt from reporting and from registration.

Herbicide Behavior in the Environment

Herbicide behavior in the environment is dependent on many things. Degradation rates, solubility, soil sorption capacity, climate, soil type, organic matter, etc, can all play a role in how a herbicide behaves. Potential negative effects of herbicides are easily mitigated. Today's herbicides have very high margins of safety regarding toxicity as well. Knowing how herbicides behave and understanding their toxicology will significantly add to your skill set.

Degradation

Herbicides are broken down in the environment in several ways. The main method of breakdown is microbial (Dreistadt 2013). Microorganisms in the soil rapidly break down most herbicides and in some cases soil arthropods actually utilize them as a food source (Busse, Rapaport & Powers 2000). The second method of breakdown is photolysis, breakdown from light. Not all herbicides photo-degrade. Herbicide breakdown in water is mainly through photolysis and in most cases is fairly rapid (Rhodes 1980).

The length of times it takes a herbicide to break down is denoted by the half-life, the time it takes for 50 percent of the active ingredient to break down in the environment (Dreistadt 2013). Half-lives can range anywhere from a couple of days to six months or more depending on the product, the environment and microbial population. Typically soil active herbicides have the longest half-lives as they are designed to last longer to provide lasting residual control.

Mobility

How mobile herbicides are in forest soils depends on the inherent properties of the herbicide and the environment. Mobility in the soil is influenced by solubility, degradation rate, ability to adsorb to soil particles, soil texture and type, pH, organic matter, slope and precipitation (Beaudry 1990, Neary, Bush &

Douglas 1983). Sandy well drained soils are the most prone to herbicide leaching, and clays are the least. Foliar active products pose little risk from leaching due to very rapid degradation rates. Soil active herbicides are more prone to movement depending on the product. It is important to realize that mobility is strongly influenced by site and that all sites are different. Looking at one or two lab derived indicators of mobility may not give an accurate depiction of what may occur under field conditions.

Toxicity

Herbicides have to pass through over 150 tests to even be considered for federal registration. California has its own testing requirements in addition to the federal ones. Every herbicide's toxicity is carefully evaluated for being a potential harm to human, animal, insect and aquatic life. Toxicity is evaluated for both acute (short-term exposure) and chronic (long-term exposure) hazards. Toxicity information can be found on each product's safety data sheet (SDS). Some of the data collected includes testing for carcinogenicity, teratogenicity, mutagenicity, reproductive effects, endocrine disruption, eye and skin hazards, etc.

Measures of toxicity are usually expressed in milligrams of active ingredient per kilogram of body weight. LC-50 and LD-50 are two frequently used terms that define the toxicity of an active ingredient. LC-50 is the lethal concentration in water required to kill 50 percent of a certain aquatic population of organism, and LD-50 is the lethal concentration required to kill 50 percent of a terrestrial organism (Table 8.2). Another useful term to know is the NOEL. This is the "no observable effect level", defined as the highest concentration of pesticide that did not produce any negative health effects. When used at labeled rates, today's herbicides pose little threat to the environment.

Table 8.2 Relative toxicities of forestry herbicides compared to several common chemicals.

Active Ingredient	LD-50 mg/kg Oral Rat	Source
2,4-D ester	1380	Weedone LV-6 MSDS
aminopyralid	>5000	Milestone MSDS
aspirin	200	aspirin MSDS
atrazine	>2000	Atrazine 4L MSDS
caffeine	192	caffeine MSDS
clopyralid	>5000	Transline MSDS
fluroxypyr	>5000	Vista XRT MSDS
glyphosate	>5000	Accord XRT II MSDS
hexazinone	1310	Velpar DF MSDS
imazapyr	>5000	Polaris AC MSDS
nicotine	50	nicotine MSDS
oxyfluorfen	>5000	GoalTender MSDS
penoxsulam	>5000	Sapphire MSDS
salt	3000	salt MSDS
sulfometuron-methyl	>5000	Oust XP MSDS
triclopyr ester	2966	Forestry Garlon XRT MSDS
vitamin D	42	vitamin D MSDS

Source: MSDS – Material Safety Data Sheets with the official chemical hazard information

Resource Protection Measures for Chemical Methods

There are many resources and sensitive areas that as a land-manager you may wish to remain pesticide free. Protection of these areas is a relatively simple task, and there are a variety of methods that can be used to protect resources, wildlife and property. One of the most valuable documents you should have in your management plan is a list of your company's mitigation measures regarding pesticide applications. Documenting what you do in practice is a necessity, both from a best management practice (BMP) and liability standpoint.

Buffers

Buffers are a designated distance or area of land designed to protect resources, people or property from contact with pesticides. It does not necessarily mean a pesticide free zone. The goal of buffers is to protect an area of concern. A 100 foot buffer, for example, may be used to protect a stream course. The applicator may stop spraying at 100 feet allowing some residue to drift into the buffer zone, but the stream course would still remain pesticide free. There is a major difference between a buffer and a pesticide free zone.

Buffers are the simplest way to protect areas of concern (Figure 8.1).

Figure 8.1 Aerial buffer along a streamcourse. Photo courtesy of John Mateski, Western Helicopter.

In general, aerial buffers tend to be larger than buffers for ground applications, and buffer size can differ between foliar and soil active chemicals. Soil active herbicides generally have larger buffers than foliar active products because soil active herbicides can move in the soil profile but foliar active products cannot. For soil active herbicides, buffer size tends to range between 50 and 150 feet for aerial applications and 50 to 100 feet for ground applications. Foliar active buffers can range from 25 to 100 feet for aerials applications and as close as ten feet or less for ground applications. These distance examples are just to give an idea of what has been used as part of industry BMP's in the past. Buffer size may be more or less depending on the land owner's practices unless it is specified on the product label.

Drift Mitigation

Drift is one of the main areas of concern regarding pesticide applications. There are many ways to mitigate drift and this is where it helps to first have your mitigation measures identified in a written plan. This plan will not only help foresters in the field but can also serve as a living document in legal matters.

Drop size has a major effect on drift. Volume median diameter (VMD) is the drop size where 50 percent of the spray volume is in droplet sizes less than the VMD and 50 percent of the spray volume is in droplet sizes larger than the VMD. As VMD decreases, the percentage of small spray droplets increases. Drop sizes less than 154µm are most prone drift (Yates, Cowden & Akesson 1985, Barry 1984). By minimizing this part of the droplet spectrum, drift can be substantially reduced.

There are many different ways to minimize the number of fine drops. As discussed earlier, nozzle size, nozzle angle, air or ground speed, pressure, boom length and humidity can all affect drop size. Nozzle orifice size is the most obvious way to manipulate drop size. The larger the nozzle orifice, the larger the VMD, and hence fewer small drops prone to drift. It is very important to know what nozzle systems your spray applicators are using and what drop size range they produce. Nozzle angle has a major effect on drop size. Nozzles angled straight back (zero degrees) on an aerial spray boom produced a VMD roughly double that of nozzles angled back at 45 degrees in wind tunnel tests which were used to simulate conditions under aerial applications (Yates, Cowden & Akesson 1985).

Increasing air or ground speed increases the number of fine drops due to increased shear of the spray solution at the nozzle. Increases in pressure will have a similar effect. As pressure is increased, fracturing of the spray solution increases, producing more fine drops. Boom lengths limited to three quarters of the rotor length for helicopter applications will also reduce the number of fine drops by reducing rotor wash at the ends of the spray swath. Making applications in higher humidity ranges that reduce the amount of droplet evaporation during flight, will also reduce the amount of smaller drops (Barry 1984).

One of the most important features on modern helicopter boom systems is the advent of the split boom (Figure 8.2). Split boom applications allow for half the boom to be shut off during application. The result is the part of the swath directly under the body of the helicopter in the center of the boom is free from rotor wash. The result is a spray pattern that falls virtually straight down (Figure 8.3). Buffer strips can be flown with the working half of the boom on the opposite side of the area of concern so that any rotor wash is concentrated on the side of the helicopter furthest away from the protected area.

Figure 8.2 Example of a split boom application. Photo courtesy of John Mateski, Western Helicopter.

Figure 8.3 An example of the precision that is achievable with aerial applications. Photo courtesy of John Mateski, Western Helicopter.

Drift control agents can also be added to the spray solution to reduce drift by increasing the formulation VMD's. Drift control agents reduce the number of fine droplets primarily by increasing the surface tension of the spray solution (Sparks et al. 1988). Spray additives are usually cost effective and cheap to reduce drift, however, conifer tolerance can also be affected (Fredrickson 1994).

Weather Guidelines

To insure safe and effective pesticide applications, it is critical to have a clearly defined set of weather guidelines. Limits on wind speed, temperature, humidity, precipitation and avoidance of inversions should be clearly addressed. Field foresters managing spray projects should also have forms in the field to document the actual conditions that were occurring at the time of application. Portable hand held weather gauges should also be available to accurately document the weather conditions on site. It should also be noted that weather can also be used to mitigate potential concerns. Spraying when light winds are blowing away from areas of concern is one example.

Project Layout and Planning

Too much emphasis can not be placed on the importance of proper project layout and planning to mitigate any potential issues. After the spray plans have been developed for any given area, detailed reconnaissance of the spray areas need to be completed on the ground. Foresters should be looking for any areas of concern such as water courses, springs, wells, property lines, ditches, residences, or other issues that may require protection.

All heliports, water sources and batching areas should be identified and mapped ahead of time. All roads should be driven and checked for hazards prior to the start of the project. Detailed contract maps need to be made that include the spray units along with all water courses, lakes, ponds, heliports, roads, batching areas, property lines, heliports and anything else relevant to the project. The contract needs to have strict guidelines regarding weather and spraying conditions, chemical handling and storage, production rates, safety and record keeping responsibilities. Detailed unit prescriptions regarding pesticide products and rates to be used need to be provided in writing. One of the most important safety mitigation measures is to have a written spill plan and spill kit in case of emergency that clearly defines procedures, personal protective equipment and contact information needed in the event of a spill.

Developing a field packet for both the forester on the ground and the spray applicator insures that everyone has all of the pertinent information they will need to complete the project safely and effectively. Field packets should include a copy of the contract, unit maps, spray recommendations and prescriptions, restricted materials permits and site identification numbers, pesticide labels and material safety data sheets, a copy of the spill plan, any necessary permits and weather and application summary forms.

Weather and application records with all pertinent pesticide use data and conditions should be kept daily. Foresters also need to be sure to read and follow all label directions for any pesticide products they are using.

The final and perhaps most important mitigation measure is to physically show the applicator or pilot the units to be sprayed and any areas within that need protection. Do not rely on word of mouth or pictures on a map to convey the message. The liability is too great to not take the time make sure the applicator is fully aware of all sensitive areas and unit boundaries that need to be avoided. Having radio communication with the pilot will also help answer any questions during the application. Portable radios should be supplied to the forester, pilot and batch truck driver to further reduce any potential risks.

On board global positioning systems (GPS) are commonly used to refine targeted aerial application of herbicides so that sensitive areas and areas with desirable vegetation can be avoided. Aerial applicators that use GPS technology should be supplied with geographic information system (GIS) shape files that show the application area, all buffer zones and the heliports that are to be used for the job. Shape files help in the application process as they show on the map where the helicopter has applied material as the application occurs. This allows the pilot and the forester to review the application and correct skips before leaving the application site.

Chemical Site Preparation (Pre-planting) vs. Release Applications (Post-planting)

The type of application and chemical choices foresters will make is largely based on whether the needed treatments are pre-plant (site preparation) or post-plant (release). Once conifers are established on a site, chemical choices and application methods are much more limited due to conifer tolerance issues (Table 8.3).

Table 8.3 Conifer tolerance to forestry herbicides by activity type and season. * conifer tolerance to glyphosate is low until trees have set bud and hardened off in the late summer to fall. ** Hexazinone tolerance varies by conifer species. See Table 8.4

Active Ingredient	Soil Active Conifer Tolerance	Foliar Active Conifer Tolerance	Timing of Highest Tolerance
2,4-D ester	n/a	low	dormant season
aminopyralid	moderate	low	spring/fall
atrazine	high	high	spring/fall
clopyralid	high	high	spring/fall
fluroxypyr	n/a	low/mod	dormant season
glyphosate	n/a	* low/high	post bud set in the fall
hexazinone	** moderate	moderate	spring/fall
imazapyr	low	very low	pre-harvest
oxyfluorfen	high	high	spring/fall
penoxsulam	high	high	spring/fall
sulfometuron-methyl	low/moderate	low/moderate	spring/fall Coast only
triclopyr ester	n/a	low	dormant season

The most effective and efficient vegetation control is usually achieved through good chemical site preparation. The cost of release treatments on a per acre basis is generally much higher than pre planting treatments and the effective control is often lower.

Site Preparation

Chemical site preparation occurs prior to or immediately after planting of any conifer seedlings to assure plantation establishment. These treatments are initially used to control any vegetation that would prevent initial seedling establishment. Site preparation treatments may be applied by air or by ground and may be done prior to, or after logging operations occur. Any vegetation management that is done after the seedlings have been successfully established is considered release.

Pre-Harvest Site Preparation

One of the most effective and efficient methods of forest weed control is pre-harvest site preparation. This method was adapted from mid-rotation release treatments in the southeastern United States and from vegetation management research conducted on bear clover with glyphosate in the northern Sierra Nevada Range in California (Fredrickson 1994, Jackson & Lemon 1986). The process involves treating the most difficult to control woody brush species such as tan oak, golden chinquapin, snowbrush, whitethorn, etc, at least one year prior to logging as an under-story treatment in the stand to be harvested.

There are many benefits from a pre-harvest site preparation system.. The choice of chemical at this stage of the reforestation effort is basically open to any product registered in forestry for site preparation, as conifer tolerance is not an issue. A useful online reference document for the different herbicides described in this chapter is the ‘Weed Control Methods Handbook’ (Tu, et al. 2001). The primary herbicide used in forestry applications is imazapyr due to its unparalleled efficacy on difficult to control brush. Since imazapyr has conifer tolerance issues from both its foliar and soil activity, it is well suited for pre-harvest application where it will not damage young conifer trees. Prior to the registration of imazapyr in California and the development of pre-harvest applications, no herbicide registered could completely control any of the most difficult woody brush species mentioned above. Treatments with glyphosate, triclopyr, 2,4-D and hexazinone would cause initial brownout, but would not completely kill the root system. Rapid re-sprouting would occur and the need for re-treatments was necessary Fredrickson (2004) showed that units that were pre-treated with imazapyr saved on the average of $200 per acre due to a decrease in release treatment need over the first ten years of plantation establishment compared to non-pre-treated units and units that had been pre-treated with herbicides other than imazapyr.

The registration of imazapyr in California in both the original water soluble (Arsenal AC) and oil soluble (Chopper) formulations provided new tools that could completely control the most difficult to control species. Since imazapyr will also kill conifer seedlings, it can not be sprayed over seedlings. Post planting release treatments are also not possible due to soil uptake of the long lasting imazapyr in most soils in California. Post-logging site preparation applications made the year prior to planting can still cause significant damage from soil uptake in planted seedlings. Even worse damage can occur from foliar contact. Therefore the only practical application timing is pre-harvest.

Pre-harvest applications can be made with other herbicides as well depending on the type of vegetation present. For example, if under-story vegetation is dominated by manzanita or squaw carpet, 2,4-D or fluroxypyr applications would suffice. For heavy deerbrush or snowberry populations, glyphosate could be used. The use of imazapyr broadens the spectrum of control so much and so effectively that it is a rare occurrence for it not to be part of the prescription alone or in combination with other products. Tank mixes with imazapyr, glyphosate and a methylated seed oil greatly broaden the control spectrum and are commonly used in pre-harvest site preparation applications with very good results. When using imazapyr, the oil soluble formulation should be used for evergreen brush in combination with a methylated seed oil. The water soluble formulation does not work well on evergreen brush, but can be used for hack and squirt treatments or for foliar treatment on deciduous brush.

Two predominant application methods can be used with pre-harvest applications. Some method of foliar treatment is typically used to control smaller woody brush. Hack and squirt treatments involve the injection of an active herbicide into a fresh cut and are used to control large woody brush, and sprouting hardwood clumps or hardwood trees. The timing of foliar applications should be during the late spring to late summer when deciduous woody is fully leafed out and the maximum amount of vegetation has germinated on the site. Hack and squirt applications can be done almost year round, with the exception of the spring sap-flow period.

Foliar treatments with pre-harvest applications can be applied as broadcast treatments, directed treatments or a combination of both. Broadcast applications can be applied using the waving wand method with gun-jets, OC nozzles or adjustable tips depending on the size and density of the under-story vegetation. Gun-jet or adjustable tip applications are ideal when the brush is small and the under-story is open and free of obstruction from sub-merchantable conifers or large brush. OC nozzle broadcast applications can occur in denser brush and usually provide better coverage. When there is too much interception from conifers, large brush or the under-story is comprised of the more difficult to control woody brush species, directed spray applications with flat fan nozzles are usually the best choice. Most of the time some sort of hybrid broadcast and directed application occurs where the crew can broadcast apply where the stands are open and the brush is small, and then treat larger brush in a directed fashion as it is encountered. In these circumstances usually OC or flat fan nozzles are appropriate.

When stands have a large component of hardwood trees, sprouts or saplings, hack and squirt treatments are usually required on top of any foliar treatment. Hack and squirt applications in a pre-harvest situation are much more efficient and effective than treating re-sprouting hardwood clumps after logging. Issues with conifer tolerance are also avoided. Depending on the density of hardwoods in the stand, crews can either apply the foliar treatments first and then go back through with the hack and squirt treatment, or if there are not many hardwoods several people on the crew could be designated to hack and squirt while the others do the foliar application.

Figure 8.4 A typical forestry hack and squirt set up.

Figure 8.5 Hacks should be spaced evenly around the circumference of the tree and hacked deep enough to penetrate through the bark to the cambium.

A complicating factor with pre-harvest applications is the logistics surrounding the harvest plan completion, logging schedule and accessibility. In California, the Timber Harvest Plan approval process and all botanical surveys must be completed prior to treatment. Unit boundaries, stream courses, exclusion areas and property lines must all be marked as well. In many cases, new roads have not been built or road reconstruction has not occurred yet. Crews may have to walk or use an ORV to gain access where roads are not available, or in some cases, it may not be possible to pre-treat some units. The treatment schedule needs to consider all of these variables to be as efficient as possible. The treatment schedule may also need to change in the common situation when the logging plan changes. Once a harvest plan is completed and ready for treatment, it is best to treat all of the units in the same year. Trying to just treat units that will be logged the following year, may result in a change of logging plans that leaves the forester with logged units that were untreated.

Although there are many logistical issues to deal with, the benefits of pre-harvest site preparation are many. The long-term reduction in release treatments also means a reduction in overall chemical use while maximizing the amount of vegetation control. A secondary benefit is a reduction in the amount of chemical needed for herbaceous site preparation treatments prior to planting. Prior to the use of pre-harvest treatments, hexazinone was often used for site prep at rates of 2.5 to 3.0 pounds active ingredient per acre as some woody brush could be controlled along with the herbaceous vegetation at those rates. Since the woody brush is already controlled by the pre-harvest treatments, the following hexazinone rates may be significantly reduced as the herbaceous vegetation is the only target and is easier to control. Another unique benefit from the applications is in regard to fall planting. Since all of the vegetation in the unit is already treated, available soil moisture is significantly improved after logging since the units sit fallow through the summer free of trees and vegetation that would otherwise remove available soil moisture. This allows for fall planting to occur earlier and with more water available for planted seedlings (Fredrickson 2002). The need for mechanical site preparation (piling) is often times reduced or removed all together. Treated brush in the under-story has a full season to die and becomes brittle by the time logging operations occur. Often times the disturbance from the heavy logging equipment is enough to crush the existing brush, making the site plantable without any further mechanical site preparation needs.

Post Harvest Site Preparation

Prior to the advent of the pre-harvest site preparation applications, post-harvest treatments were much more common than they are today. The disadvantage of treating brush after harvest operations have occurred is that the majority of plants that survived logging are damaged and do not translocate the herbicide as effectively causing reductions in control (Newton & Knight 1981). The other problem relates to woody brush that has re-sprouted from existing root stocks. In this case, there is rarely enough leaf area after logging to be able to absorb enough chemical to translocate to the existing root system. Usually two to three years of re-growth is required to match the leaf area above ground with the root system below ground to obtain good control. Most often by the time the new seedlings are to be planted, not enough time has elapsed from logging disturbance for brush to recover or achieve the ideal size for treatment.

A different challenge for post-harvest woody brush site preparation occurs after wildfires. Often times woody brush germination is promoted by fire. Seedling populations can be dense and intermingled with surviving damaged brush or woody brush that has re-sprouted from previously existing root systems. In these instances, foresters have no option but to deal with woody brush post-harvest.

If post-harvest site preparation applications must occur, it is usually best to let damaged or re-sprouting brush to recover prior to treatment. Treating brush prior to it achieving adequate leaf area will most likely result in re-sprouting and the need for repeat treatments. The downside of waiting is losing a year or more on the rotation of the new stand. In situations where woody brush germination is primarily from seed, it is most cost effective to treat immediately after germination occurs. Treating seedling woody brush when it is small is magnitudes more cost effective and efficacious than waiting until brush gets larger. With some species on some sites, treatment prior to germination with a soil active herbicide may also be effective.

Whether or not woody brush has been controlled pre or post-harvest, some type of treatment to control herbaceous vegetation prior to planting is also required. The competitive ability of herbaceous vegetation on seedling survival and growth has been well documented (Rose & Ketchum 2002, White, Witherspoon-Joos & Newton 1990, White & Newton 1989, Peterson, Newton & Zedeker 1988, Newton & Preest 1988). Even in the wetter climates of western Oregon Douglas-fir seedlings experienced a 217 percent gain in volume when herbaceous vegetation was controlled over the first three years. Vegetation control on drier sites has been shown to triple volume growth of ponderosa pine (Powers & Reynolds 1999).

Post-harvest site preparation treatments can be applied by either air or hand. Aerial applications are applied broadcast. Suitability of aerial applications on brush is dependent on the type and size of brush. Usually evergreen species of woody brush are controlled more effectively with hand applications. Imazapyr treatments by air are highly effective on evergreen brush, but they should not be applied the year prior to planting due to potential conifer damage from soil uptake of Imazapyr. Treatments applied earlier than that should have no residual effect on conifers. Site preparation application by air over species such as deer brush or snow berry with glyphosate can be highly effective as can 2,4-D over smaller manzanita. When dealing with seedling woody brush, the smaller the plants, the more efficacious the treatment will be. Larger or re-sprouting brush from root stocks would probably be more suited to hand treatments.

Site preparation treatments on woody brush by hand can be applied by either broadcast or directed methods, depending on the size and species of brush. Similar to the aerial applications, broadcast treatments for brush by hand should focus on the easier to control species such as deer brush, snow berry or manzanita. The more difficult to control evergreen brush or hardwood sprout clumps should most likely have a directed hand spray treatment unless imazapyr is used more than one year prior to planting. Hardwood sprout clumps should also be treated with a directed hand spray or basal treatment depending on the species.

Herbaceous treatments either by air or by hand should be applied with a broadcast method. Soil active herbicides are used for broadcast herbaceous treatments almost exclusively. Occasionally glyphosate can be used in a post-emergent setting, but this is not the preferred treatment as it does not provide any soil residual. Soil active herbicides are dependent on rain to activate and the timing of application is critical to maximize the chances of getting the correct amount. Too much or too little rain can severely impact efficacy. Usually between three and twenty inches of rain is ideal for soil active products. The timing of application depends on seasonal rainfall total, elevation, snow level, access and soil type. Low elevation units that receive a high seasonal rainfall total should be applied in the spring at a time when the forester thinks the necessary amount of rain can be achieved. High elevation units that receive mostly snow should be applied in the fall to assure adequate moisture is received. Access to these sites in the spring may be impossible due to snow until after the spring rains have ceased. Areas on the east side of the Cascade or Sierra Nevada Range should also be applied in the fall as the majority of these sites are in high elevation, low rainfall sites that may only receive 15 or 20 inches of precipitation annually. A general rule of thumb that may be utilized in most areas is units under 4000 feet elevation should be treated with residual herbicides in the spring and those over 4000 feet elevation should be treated in the fall.

When using soil active herbicides for pre-plant site preparation, it is extremely important to know what species of conifers are going to be planted on the treated site and what their tolerance is to the chemicals being used (Table 8.4). While hexazinone provides the best overall control of any of the soil active herbicides, Douglas-fir (*Pseudotsuga menziesii*), white fir (*abies concolor*), sugar pine (*Pinus lambertiana*), incense cedar (*Calocedrus decurrens*) and western larch (*Larix occidentalis*) are to some degree intolerant to hexazinone. Some tolerance issues can be mitigated through rate reductions for species such as Douglas-fir and white fir, while other species have almost no tolerance for it. The use of sulfometuron methyl in the interior parts of California and southwest Oregon can cause root growth inhibition in almost all conifer species. The only two soil active herbicides registered for use in California that have virtually no tolerance issues are atrazine and oxyfluorfen plus penoxsulam.

Table 8.4 Tolerance of commercial conifers for the main soil active herbicides used in site preparation. * Douglas-fir tolerance to sulfometuron-methyl is low in the interior parts of California and moderate on the Coast.

Conifer Species	Hexazinone	Atrazine	Sulfometuron Methyl	Oxyfluorfen + Penoxsulam
ponderosa pine	high	high	low	high
Douglas-fir	moderate	high	* low/moderate	high
white fir	low	high	low	high
incense cedar	low	high	low	high
sugar pine	very low	high	low	high
red fir	moderate	high	low	high
redwood	very low	high	moderate	high

Overall, site preparation applications have the most flexibility of any chemical treatments due to the lack of conifer seedlings and tolerance issues. The best money a forester can spend is on good site preparation. Controlling competing vegetation correctly from the start will save numerous applications, reduce overall herbicide use, increase survival and growth, reduce applicator exposure, and save thousands of dollars for the land owner. Remember this quote from Professor Emeritus Michael Newton of Oregon State University. "If you have a large release program, you're probably screwing up."

Release Applications

Weed control treatments after seedlings have been successfully established are referred to as release treatments. The trees are being released from the competitive effects of vegetation. These treatments can be the most expensive investment of any reforestation effort. Chemical choices are limited due to conifer tolerance issues and many of the treatments must be applied by hand (Table 8.4). Often times certain woody brush species cannot be effectively controlled because the ideal herbicides are not available for release.

Release treatments are most beneficial early in a plantations life. Delaying release treatments increases costs as well as diminishes the growth response of crop trees (Fiddler & McDonald 1999, Newton & Knight 1981). Significant increases in survival, stem diameter, height and volume have been well documented for herbicide release treatments in California (Fiddler, McDonald & Mori 2000, McDonald & Fiddler 1999, McDonald & Everest 1996). While some type of release treatment during plantation establishment is usually required, a truly successful reforestation program will minimize release needs as much as possible through good site preparation.

Chemical release has several advantages over other methods of release such as mechanical or manual methods. Effectiveness and cost are the major advantages, but chemical release treatments also have the least impact on the forest soil in terms of generating erosion or new infestations of weed species that require disturbance to germinate (Newton & Knight 1981).

Aerial Release Applications

Aerial release applications are the most cost effective method of release, but they are also the most limited. They are limited due to conifer tolerance issues with over the top applications. Soil active herbicides including atrazine and oxyfluorfen plus penoxsulam can be applied over the top of all conifers, but options with hexazinone and sulfometuron methyl are more limited. Surfactants are not usually needed with soil active products but should be avoided in most cases because they can reduce conifer tolerance. The exceptions to this are with atrazine or oxyfluorfen plus penoxsulam.

Not all herbicides are registered or have conifer tolerance for applications over the top of planted conifers. Two of the more common ones that do are clopyralid and glyphosate. With glyphosate applications, timing is the most critical factor to avoid conifer injury. Broadcast applications must be applied in the late summer or early fall after conifer seedlings have set bud and hardened off for the year. Application made earlier than that will result in conifer injury or death. Applications over the top of newly planted conifers with glyphosate products is not advisable and restricted on most labels.

The type of glyphosate product applied is also critical. Most formulations of glyphosate do not have an aerial release label approved for over the top applications. Rodeo is a non-surfactant formulation of glyphosate that is labeled for aerial release treatments. Since no surfactant is formulated into the product, one must be added to achieve adequate efficacy on the vegetation. Additional care must be taken in choosing an adjuvant. Most surfactants or adjuvants will increase conifer injury when added to a glyphosate formulation. Historically, only tallow-amine surfactants have had enough conifer tolerance to be safely added or formulated into glyphosate formulations. Currently Penetron is the only tallow-amine surfactant labeled in California for aerial release treatments with glyphosate. Other types of adjuvants such as drift control additives, acidifiers or oils can also increase the risk of conifer injury. With the large number of generic formulations of glyphosate, care must be taken to insure the product chosen is labeled for aerial release.

The species of vegetation that may be controlled with aerial glyphosate release applications is also limited to those species previously mentioned. Herbaceous vegetation control with soil active products does not differ from what was discussed for aerial site preparation applications.

Hand Release Applications

When aerial applications cannot be used or foliar herbicide tolerance to conifers is an issue, treatments must be applied by hand. All hand application methods are available for release needs. Similar to aerial applications, broadcast hand treatments are limited to those herbicides which have conifer tolerance when applied over the top such as glyphosate in the fall or the soil active herbicides as previously mentioned.

If more difficult species are present, another application method must be utilized. Where species such as tan oak, snowbrush, golden chinquapin or live oak (*Quercus chrysolepis*) are present, foresters are faced with tougher challenges. Where these species would have been easily controlled with imazapyr in a pre-harvest application, conifer tolerance issues prevent it from being used in most areas for release. In this case, the forester must determine the most efficacious and cost effective method to use. Choosing the type of herbicide is to a large degree dictated by the type of vegetation that is in need of control. Identification of a complex series of weed pests that are present in the application area is important. For example, a unit the has predominantly manzanita, snowbrush and chinquapin, the best choice of a herbicide for a release treatment might be 2,4-D plus triclopyr in the fall. If that vegetative complex also included cherry and deerbrush, it may be more prudent to apply glyphosate with a methylated seed oil during the growing season. Application timing and chemical choice are in some instances different in separate regions of California. It is best to consult local foresters that are licensed pest control advisors in any given area.

For these difficult to control evergreen species, in some areas directed spray applications of growth regulator herbicides or a high concentration glyphosate treatment may be the best option, in other areas basal bark or spot-gun applications may be best.

When glyphosate became generic the price dropped significantly. Most glyphosate products were always labeled for high concentration directed spray applications in the five to ten percent solution range, but prior to going off patent it was cost prohibitive for anything but scattered black oak treatments. The cost savings of generic products allowed foresters to treat larger areas and more species with higher rates of glyphosate, usually in combination with a methylated seed oil. Glyphosate is one of the safest and shortest lasting herbicides in the environment. It is also non-mobile and poses little risk to fish or wildlife when applied according to the label. Therefore, these applications had many attracting qualities. Timing is critical with glyphosate applications. Treatments from late spring to mid-summer are most effective on evergreens such as snowbrush, whitethorn and manzanita. Treatments later in the season have proven to be less effective in September and ineffective after the onset of cold weather. Tan oak and golden chinquapin are only partially controlled with glyphosate. These glyphosate treatments can reduce the amount of re-sprouting that occurs with snowbrush and whitethorn compared to treatment with growth regulators. Early season glyphosate treatments also allow foresters to control any existing herbaceous vegetation with lower volumes and glyphosate rates.

The high concentration glyphosate treatments can provide a very broad spectrum of control, however there is a tradeoff. The amount of solution volume required to control the more difficult evergreen species can increase labor costs significantly. These are not the most efficient applications from a labor stand point. Applicators also need to be careful not to exceed maximum label rates. The other drawback is that the timing for the best efficacy occurs when the tree seedlings are actively growing and the most intolerant of the chemical. Seedling protection is required when these applications occur. Some type of shield plus a spray bottle filled with water to wash trees accidentally sprayed should be carried.

High concentration glyphosate treatments have a very good fit for re-sprouting black oak clumps provided they are not too large. Ten percent solutions of glyphosate will adequately control black oak clumps and are applied at extremely low volumes and highly cost effective. Clumps can usually be treated safely to a height of about five or six feet tall. Once they grow larger than that too much over-spray occurs that may potentially injure conifer seedlings. These treatments are not as effective on other deciduous hardwoods such as dogwood or big leaf maple. Lower concentration glyphosate applications should be used if the target vegetation is mainly comprised of herbaceous vegetation and deciduous woody brush other than hardwood sprouts. Seedling protection is still required.

Growth regulator herbicides such as triclopyr, 2,4-D and fluroxypyr can also be used for directed spray applications when there is evergreen woody brush present. Foliar applications with growth regulator products on deciduous brush are not recommended due to high rates of re-sprouting following application. Growth regulators provide excellent burn down of most all vegetation and completely control some woody evergreens such as manzanita and squaw carpet. Results on most woody evergreen species result in at least some re-sprouting. Repeat treatments may be necessary on species such as snowbrush, chinquapin, tan oak and whitethorn. Seedlings are also highly sensitive to triclopyr and 2,4-D, and slightly less so with fluroxypyr but seedling protection is required in all cases. Volatilization is also a concern and applying in temperatures over 75 degrees should not occur.

Where there is a mix of deciduous and evergreen woody brush, growth regulator herbicides should never be mixed with systemic products such as glyphosate or imazapyr. The growth regulators do so much damage to the translocating tissue in the deciduous plants that neither glyphosate or imazapyr can get where it needs to go to work in the plant. Deciduous plants will re-sprout much like when treated with growth regulators alone.

Spot-gun treatments with liquid hexazinone can provide a highly effective and efficient treatment if the brush is not heavy. Snowbrush is usually the primary target and is controlled very effectively. Spot-gun can also be used on other brush such as deer brush, whitethorn and manzanita. If cover is very heavy, directed applications with glyphosate or growth regulators may have to be used.

Basal bark or hack and squirt applications may be utilized on more difficult to control hardwood sprouts such as big leaf maple, dogwood or live oak. Their use depends on the efficacy in the region and the conifer tolerance of the species planted on site. In general, hack and squirt should not be used with imazapyr where ponderosa pine is planted. Damage may not appear immediately, but imazapyr flashback can show up several years after the application. Basal bark or high concentration glyphosate applications may be more appropriate. Without the use of imazapyr, controlling hardwood sprouts other than black oak is difficult.

Cut stump applications for release are rarely used in forestry due to cost, but may occasionally have a fit if the amount of saw work is light.

It may appear that achieving adequate control with release applications is difficult. It is possible, but definitely more difficult than controlling vegetation as a site preparation application. The presence of conifer seedlings severely limits management options compared to site preparation. It is not hard to see that by controlling the more difficult evergreen species effectively during site preparation, cost, chemical used, worker exposure and vegetative cover can all be reduced while enhancing conifer survival and growth.

Project Level Considerations Before Choosing a Chemical Control Method

Treatment Objectives

The first thing you need to determine is the species of vegetation you are trying to control. There is no magic bullet. In defining your objectives for the treatment, you need to evaluate the vegetation complex and determine which species are the greatest problems. The most efficacious method can then be determined. Many species are not controllable with aerial applications, some are limited to certain types of hand treatments, and for some, there may not be a suitable control technique at all. Your objective is to determine what the main treatment need is and to do the very best that you can.

Cost

Your budget will dictate much of what you can and can't do as far as application methods go. Aerial applications are the least cost option due to the amount of area that can be covered in a very short amount of time. Aerial forestry applications are mainly limited to helicopters due to the topography, but where large tracts of flat clean ground exist, fixed wing aircraft applications may be possible. Ground treatments with a tractor or other ground equipment are fairly cost effective, but also very limited in use due to topography, slash loads and stumps. In increasing order of cost, application methods range from fixed wing aircraft to helicopter, then to tractor or other type of ground machine, with hand applications usually being the most expensive.

Much of the cost of hand applications depends on the type of treatment that is being done. Directed (or spot) treatments where individual plants are specifically being treated are the most expensive. Broadcast applications by hand are very efficient and can in certain types of treatments rival helicopter costs. Familiarity with all the different types of application methods and their availability is critical. When conducting sprays by hand, having a crew that can apply them efficiently and effectively will often reduce application costs more than anything else you could do.

Effectiveness

The different application methods will have varying results compared to each other mainly due to differences in coverage. This is mainly true for foliar applications where coverage on leaf surfaces is critical. Coverage from aerial applications is not as consistent, or as thorough as coverage from hand applications. When foliar contact herbicides like glyphosate, imazapyr, triclopyr, fluroxypyr or 2,4-D are used, efficacy is usually best with hand treatments compared to aerial applications depending on the type of vegetation treated.

The type and size of vegetation will also determine how effective an application technique will be. As woody brush gets larger, it gets more difficult to control by aerial methods. Deerbrush (*Ceanothus integerrimus*) is fairly easy to control by air with glyphosate when it is small. If large deerbrush is treated by air, it may only top-kill plants and result in subsequent resprouting. Evergreen brush such as tan oak (*Lithocarpus densiflorus*), golden chinquapin (*Chrysolepis chrysophylla*) and snowbrush (*Ceanothus velutinus*) are very difficult to control with aerial methods depending on the type of herbicide used.

Coverage for soil active herbicides like hexazinone, sulfometuron, oxyfluorfen, penoxsulam and atrazine is less critical than foliar applied herbicides. Soil active products tend to spread in soil when in contact with moisture, and are much more forgiving if coverage is not complete. Application method makes much less of a difference with soil active products provided that the application is done correctly. The greatest risk with hand applications and soil active products are skips and proper calibration.

Conifer Tolerance

Herbicide choice and conifer tolerance will also dictate what application methods you can and can't use. Broadcast applications over the top of established seedlings by aerial or ground methods are not possible with herbicides that provide little conifer safety. In this case, directed hand treatments may be the only option. Time of season may also dictate when over the top applications can occur with certain herbicides like glyphosate. Conifers are tolerant to over the top applications of glyphosate in the fall, after buds have hardened off. If treatments occur prior to that, conifer damage or mortality will occur.

Scope of Project

What type of application method you use may depend on the size of project and availability of local applicators. Aerial applications are well suited for large projects. Helicopter applications can usually treat up to 300 or more acres per day. Hand crews trained to do efficient broadcast applications can treat between 100 and 150 acres per day. If directed hand spraying is required, production rates may drop down between 30 and 60 acres per day depending on the size and density of brush, access, etc. Scheduling out your project to make sure you complete your objectives is critical. You should have a production plan and make sure contractors are completing the required amount of acres per day, weather permitting.

Logistics

Logistical concerns may also influence the type of application method you use. Access is critical for ground spraying operations. Without good access, costs can rapidly get out of control. In this case, aerial applications may be more appropriate. To make aerial applications efficient, heliports, road access, water sources, staging and storage areas all must be available and in good condition for a successful program.

Liability Issues

With any spraying operation, there are potential liability concerns. The land manager's responsibility is to anticipate and mitigate these concerns and therefore minimize liability to the landowner and risks to the environment. The risk of liability can also dictate what type of application method you choose. If you are spraying close to adjacent dwellings, a critical analysis of application method should be conducted, and aerial applications should probably not be the method of choice. Ground applications are a good choice when spraying around areas with water, wells, domestic ditches, property lines or other areas where herbicide buffers need to be precisely applied. Many times a combination of hand and aerial treatments can be used, where hand treatments are applied around sensitive areas and aerial methods are used to treat the remaining areas. Aerial applications can be made very precisely, but alleviating concerns utilizing alternative methods can go a long way in gaining trust and ensuring future projects progress according to plan.

Site Specific Issues with Chemical Vegetation Control

Variables That May Affect Chemical Applications

There are many things to consider that may affect your chemical application, any one of which may negatively affect the outcome if not considered and planned for. Probably the most important physical influence on spray operations is the weather. Weather can influence everything from efficacy to drift. As a land manager, it is imperative to know the conditions to avoid to achieve a safe and successful application.

Temperature can influence applications in several ways. As temperatures increase, smaller spray particles are suspended in the air for longer periods of time and can drift away from the application site (Barry 1984). Generally, as temperatures increase, the risk of offsite movement increases. Herbicides that are volatile ester formulations are subject to increased volatilization rates as temperature increases and humidity decreases. Volatilization occurs when temperatures rise, turning the ester herbicide formulation from a liquid into a gas phase (Gratkowski & Stewart 1973). The gas phase of the herbicide maintains its phytotoxic properties and can move off the application site causing damage to desirable vegetation. Volatilization can be exacerbated on open rocky sites or sites with light colored soils with little ground cover. Application of these types of chemical during extended periods of hot, dry weather may be infeasible. The herbicide labels of volatile esters often restrict application if the temperature is in excess of 75 degrees or is expected to exceed 75 degrees immediately after application. Most herbicide formulations now are either low volatile esters or amines. Low volatile esters have the potential to volatilize and cause off-site movement of the herbicide under adverse conditions, but are less likely to do so than regular ester formulations. Volatilization with amine formulations of herbicides are negligible and are more suitable for use in areas or under conditions where volatilization would cause an adverse effect. New choline formulations of herbicides almost do not volatilize at all.

Humidity and wind also play an important role in spray applications. Spray drift increases as humidity decreases and winds increase (Gratkowski & Stewart 1973), and if spray particles move offsite, both the efficacy on onsite target vegetation and the potential damage to offsite vegetation can be greatly affected. Generally, winds less than five miles per hour are acceptable for aerial applications and winds should be less than ten miles per hour for ground applications.

Temperature inversions are frequently referred to on pesticide labels as a weather condition that prohibits herbicide application. In a temperature inversion, cold air is trapped under a layer of warmer air. This phenomenon typically occurs in valleys or basins during periods of calm winds. If an application is made during a temperature inversion, spray particles can get trapped in the inversion layer and move great distances horizontally. Spraying under these conditions should be avoided due to the high potential for off-site movement (Dreistadt 2013).

Rainfall can have an effect on spray applications. For foliar active products, rainfall too soon after application can wash the active ingredient off of plant surfaces before penetration occurs, thereby reducing efficacy. Several hours are usually required for adequate drying of herbicide residues on plant tissue, but this time can be reduced with the addition of a spray adjuvant that increases penetration into leaf surfaces.

Soil active herbicides require rain to activate, and in this case, rainfall is a necessary part of the equation for successful applications. Too much or too little rain can have a major effect on efficacy and possibly conifer tolerance.

Timing

One of the most overlooked factors that contribute to successful herbicide applications is timing. Target vegetation is more or less susceptible depending on the time of year, and different types of herbicides have different application windows as well. Woody deciduous brush is usually most susceptible in late summer to early fall with systemic herbicides (Cole & Newton 1989), whereas, woody evergreen brush is usually more susceptible in the late spring to early summer with either systemic or growth regulator products (Jackson & Lemon 1986, Paley & Radosevich 1984). Herbaceous vegetation has a small treatment window in the early spring for foliar active products, before senescence occurs in the early summer.

The timing window for soil active herbicides depends on soil moisture availability, as these products require rainfall to activate. The timing usually depends on elevation, geography and annual precipitation patterns (White, Witherspoon-Joos & Newton 1990). Ideally, soil active products in lower elevations are usually applied in the spring to avoid the bulk of the winter precipitation, whereas high elevation sites where snowfall is the predominant precipitation are usually treated in the fall. It is essential to understand how much precipitation is too much or too little and base the application timing on the period you think will come closest to receiving the proper amount.

For foliar herbicide applications that are applied over the top of existing conifers as a broadcast application, the proper timing depends on when the trees are hardened off and tolerant to the herbicide. Conifer tolerance to foliar herbicides is usually greatest in the late summer or fall after buds have hardened off (Radosevich et al. 1980). The least tolerant period is when trees are actively growing. Since soil active herbicides are usually applied in the late fall or early spring when trees are still dormant, most soil active products can be applied over the top of planted seedlings without foliar injury.

Soil Type

Soil type plays a major role in how soil active herbicides work. The active ingredient in many herbicides adsorbs to organic matter in forest soils. The higher the percent organic matter, the more active ingredient is tied up in the soil and unavailable for plant uptake. Soils with high organic matter contents may require higher rates of herbicide, or the organic content may be so high that soil active herbicides may not work at all (Johnson 1987).

Soil texture also plays an important role with soil active herbicides. Soil active herbicides are more mobile in porous well drained soils with higher sand content and less mobile in soils with higher clay contents (Johnson 1987). Soils that are well drained with low organic matter contents also carry a higher risk of conifer damage due to the herbicide being more available for plant uptake. Risk of leaching also increases as organic matter decreases and porosity increases. Land managers need to be particularly concerned on steep slopes with well drained soils when there are sensitive areas that are at risk from leaching.

Topography

Topography can also play a role in how herbicides behave and can affect the quality of application. Steep slopes are more prone to leaching, especially in well drained soils or rocky sites. They are also more hazardous for the applicator, with both ground and aerial applications. Steep slopes usually require slightly larger buffers to assure contamination of watercourses does not occur. Even aspect can play a role regarding efficacy. Under drought stress conditions, hot south facing slopes can stress plants to the point that herbicide uptake is negatively affected.

Herbicide Formulation

It is important to understand how the herbicide formulation itself can affect efficacy. The herbicides used in forest applications are either liquid, granular or dry flowable formulations soluble in water. Liquid formulations are either formulated as amines or esters. Esters are soluble in oil, amines are only soluble in water. Esters can penetrate thick waxy cuticle layers on leaf surfaces easier than amine formulations, and this is why esters tend to be more efficacious on difficult to control woody evergreen brush than amine formulations. There is a drawback however. Ester formulations have a higher vapor pressure than amines and will volatilize at higher temperatures. Amines may be used at higher temperatures, but efficacy may suffer. Amines have shown excellent efficacy on deciduous woody brush or herbaceous broadleaved plants and grasses. Amine efficacy on woody evergreen brush has improved since the advent of the methylated and ethylated seed oil adjuvants.

The dry formulations present somewhat of a different challenge. With granular products that are spread over the landscapes surface and rely on rainfall to activate, the only real concern is making sure the distribution of material through the application system is adequate for even coverage. When dry products such as dry flowables, wetable powders, etc are used, constant agitation during mixing and application is critical to achieve consistent rates when applied. Today's dry flowable formulations go into solution well compared to older formulations.

Spray Application Technology

Understanding the interactions between application variables such as drop size, volume, rate and adjuvant can be very complicated and varies greatly by active ingredient and species to be controlled. However, understanding the basic principles can greatly improve both the efficiency and efficacy of applications.

Drop Size

Drop size can influence several different aspects of spray applications. For foliar applications, the smaller the drop size the greater the surface area of spray solution available to contact plant surfaces. This does not necessarily mean an increase in efficacy, just more efficient coverage of plant surfaces (Fredrickson & Newton 1998). The tradeoff is smaller drops tend to drift. Large drops reduce drift significantly but coverage is negatively affected (Akesson, Yates & Wilce 1970). For soil active herbicides, drop size does not affect efficacy, so it would make sense to use larger drop sizes to reduce risk of offsite movement.

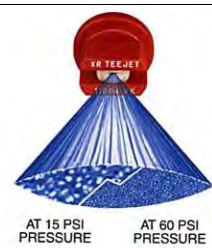
Several physical factors can influence drop size. Choice of nozzle size is the most obvious one. It is extremely important to know exactly what nozzles spray applicators are using for either ground or aerial applications. Your choice of nozzle will vary depending on the type of application you are doing. Certain applications may require smaller or larger droplets depending on the objective. The greatest liability with small drops is with aerial applications, and it is absolutely imperative that land managers are doing all they can to minimize the risk of offsite movement. Small drops should be avoided with aerial applications unless the risk of offsite movement is minimal.

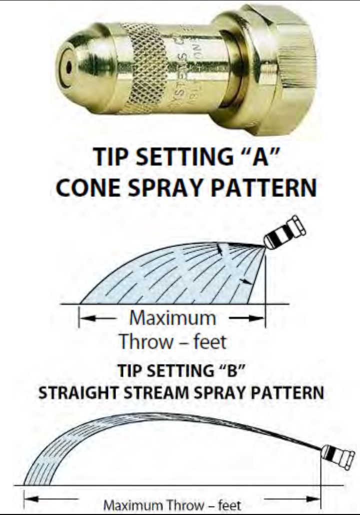
It is important to be aware of other factors that can reduce drop size. Pressure at the nozzle can affect drop size - as pressure at the nozzle increases, drop size decreases. Air or ground speed also affects drop size through shear at the nozzle. The faster the application equipment is moving, the smaller the drop size. Nozzle angle can influence drop size with aerial applications. Drop size is decreased as the nozzle angle increases from horizontal in the direction of travel. The greatest drop size is achieved with nozzles angled straight back, reducing nozzle shear (Yates, Cowden & Akesson 1985). For helicopter applications, boom length is a critical factor controlling drop size and spray deposition patterns. The shorter the boom relative to rotor length, the less rotor wash and liquid shear at the nozzle. As boom length increases, a significant vortex occurs from downward airflow created from the rotors, decreasing drop size.

Nozzle Characteristics

Since nozzle selection has the largest influence on drop size and drift, it is important to understand some basic nozzle characteristics (Table 8.5). Nozzle type will differ depending on the type of application. Selection of nozzles for aerial applications can be quite different from those used in ground treatments, although there can be some overlap depending on the application method.

Table 8.5 Common nozzle types used in forestry applications and their spray patterns.

Nozzle	Type	Pattern	Uses
11004	tapered flat fan		directed hand spraying, broadcast applications on a fixed boom.
8004	even flat fan		band applications
OC-12	off center		waving wand hand broadcast applications, roadside boom
D-6	disk		aerial broadcast, hand broadcast with a gun-jet, spot gun applications with a meter-jet

5500	adjustable tip		basal treatments, hardwood clump sprouts, waving wand hand broadcast applications

The most common nozzle used for hand directed spray treatments is the flat fan nozzle. Flat fan nozzles come in a wide range of sizes that produce anywhere from very small to very large drops. Flat fan nozzles are designated by a series of numbers. The first two or three numbers are the angle of the liquid that is emitted from the nozzle orifice. The last two numbers are the gallons per minute put out through the nozzle at a set pressure, usually 40 pounds per square inch (psi). An 8003 nozzle for example has a liquid spray angle of 80 degrees and each nozzle puts out a spray volume of 0.3 gallons per minute at 40 psi. The larger the last two numbers are, the greater the drop size. Flat fan nozzles are also made in two different spray patterns, tapered or even. Even flat fans maintain the same spray width from the center to the ends of the spray pattern. Tapered nozzles are widest in the center and get narrower at the ends of the spray patter to allow for overlap of the spray solution. Even flat fan nozzles are primarily used for banded applications in agriculture, whereas tapered nozzles are the main ones used in forestry. The specifications may vary somewhat depending on the nozzle manufacturer.

One of the most popular nozzles used for broadcast applications by ground in forestry is the off center (OC) nozzle. These nozzles produce a much different spray pattern than flat fan nozzles. The spray solution is emitted from one end of the nozzle and thrown out away from the applicator in an arcing pattern. This nozzle produces excellent coverage when the nozzle is attached to a hand held spray wand and waved side to side for broadcast applications. The nozzles are designated with two letters followed by a number. A popular off center nozzle used in forestry is an OC-12. The OC stands for "off center" and the number designates the gallons per minute emitted from one nozzle at 40 psi. In this case the 12 stands for 1.2 gallons per minute, whereas and OC-06 would emit 0.6 gallons per minute. Similar to flat fan nozzles, the larger the number, the larger the drop size.

Aerial applications in forestry primarily use some type of disk or disk core nozzle that relies on air speed and nozzle angle as well as orifice size to manipulate the spray pattern and drop size produced. Disk nozzles produce a spray pattern in the form of a stream, and when a disk core is added to the nozzle, the spray pattern produced is a cone. The cone pattern produced by disk core nozzles can either be hollow in the center or completely covered. This is the difference between a hollow or full cone nozzle. Many aerial applicators choose to apply pesticides without a core and just use the disk orifice to produce a stream from the nozzle. In this case, the applicator relies on air speed and nozzle angle to shear the stream and produce a desirable spray pattern. This significantly reduces drift by creating larger drop sizes, but coverage may be affected as well.

The most popular aerial nozzles for helicopter applications currently used are probably the D series disk nozzles. With these nozzles, the D stands for disk nozzle and the number refers to the nozzle orifice size. In this case, the number does not specifically correspond to a certain volume per minute, but to an increase in orifice diameter. A D-8 disk nozzle puts out significantly more volume and a larger drop size than a D-4 nozzle. It is important to realize that the drop size produced from the nozzle on the ground while not moving is going to be much greater than when attached to a boom at a certain angle and traveling at a relatively fast air speed. As air speed increases and the mounted nozzle angle from horizontal increases, drop size decreases. D Series nozzles are also the one nozzle that is used for both aerial and hand applications. They are the main nozzle chosen for broadcast hand applications when using the gun-jet application method.

This is just a brief explanation of how some of the more commonly used nozzles work. There are many nozzles to choose from and the designations may vary slightly, but they all work under the same general principals. The are also many specialty nozzles that may have some limited use in forestry. The importance here is to realize that the choice of nozzle can have a significant effect on the success or failure of an application. The volume, rate, efficacy, deposition and cost per acre can all be affected by nozzle choice. If a hand crew is applying herbicides and the crew members do not all have the same nozzles, application rates between applicators can vary dramatically. The same can be said for a helicopter boom that is not fitted with all the same nozzles. It is imperative to pay attention to these application parameters.

Application Volume

Changing the application volume per acre can affect several spray parameters including cost. In general, volume per acre has little effect on efficacy with a few exceptions. Glyphosate has repeatedly shown to be more effective at low volumes per acre (Cranmer & Lindscott 1990, Buhler & Burnside 1987, Ambach & Ashford 1982). More than anything, volume per acre affects coverage. Coverage increases as volume per acre increases. A fairly large portion of spray volume is lost however due to large drops splashing off of leaf surfaces (Young, Hart & Hall 1987). Volume per acre can best be managed by nozzle size and travel speed.

The main drawback of using high spray volumes is cost. As spray volume increases, the time required to spray a given area increases as does the cost per acre. This is most dramatic with hand applications. Labor costs for hand applications can easily double just by doubling the spray volume. Often times, foresters mistakenly attribute increased efficacy to increases in the volume of herbicide solution applied. In reality, this is actually due to an increase in herbicide rate from higher volumes applied. Efficiency of applications can be significantly improved with higher rates and lower spray volumes (Fredrickson 1994).

Rate

The most important variable affecting efficacy is rate (Fredrickson & Newton 1998, Fredrickson 1994). Many times an increase in volume is mistakenly given credit for increased efficacy, when it was actually the inherent rate increase with increasing volume that was responsible. The challenge for foresters is to use the least rate possible to achieve maximum efficacy, hence increasing efficiency. Most herbicides are expensive and making applications as efficient as possible can easily justify the effort.

Adjuvants

Adjuvants are any type of additive to the spray mixture that changes the physical properties of the spray solution. Surfactants, spreaders, stickers, buffering agents, etc are all adjuvants. The main adjuvant type discussed here will be surfactants. Water has a high surface tension that causes droplets to bead up on leaf surfaces. Surfactants reduce surface tension causing spray droplets to spread over leaf surfaces maximizing coverage (Hess & Faulk 1990). Surfactants also aid in penetration of waxy leaf cuticles, increasing the amount of active ingredient absorbed into the plant (Geyer & Schnerr 1988). Rainfastness can be improved with the use of adjuvants by speeding up absorption rates into plant tissues (Sundaram 1990(a), Sundaram 1990(b), Stevens & Zabkiewicz 1990).

Surfactants are classified into several types. Nonionic, cationic, silicone based, petroleum distillates and methylated or ethylated seed oils are the main types used in forestry. All reduce surface tension and cause droplet spread. The silicone-based surfactants reduce surface tension the most and hence cause the most droplet spread. However, this doesn't necessarily correspond to increased control (Fredrickson 1994, Whitson & Adam 1990, O'Sullivan et al. 1981). Many herbicides have adjuvants formulated into the product already. In many cases adding a surfactant to a product that already has a surfactant formulated into it adds no additional benefit (Fredrickson 1994, Brewster & Appleby 1990, Babiker & Duncan 1974).

Historically, non-ionic and silicone based surfactants were mainly used with water soluble amines. Petroleum or seed oil based adjuvants were primarily used with oil soluble esters. This has changed in recent times. The seed oil products tend to work well with either amines or esters. Adjuvants are usually cheap insurance but it shouldn't be taken for granted that they are increasing efficacy. Furthermore, surfactants can also have a negative effect on conifer tolerance (Fredrickson 1994).

Application Method

The application method you choose will also have an effect on the physical properties of the application, but mainly from a deposition standpoint. Treatments made by hand are going to directly deposit the spray solution exactly where it needs to go. The risk of offsite movement is minimal. Aerial applications have the most dispersion of the spray solution and while they can be applied extremely accurately, the deposition cannot be placed as accurately as hand applications. Ground applications with tractors or off road vehicles fall somewhere in the middle. The big tradeoff between the methods is cost, with hand applications being the most expensive and aerial applications being the least.

Application Methods

Aerial Applications

Aerial applications are the most efficient method of applying herbicides. Large areas can be treated in a very short period of time. Rough topography, poor access, lower cost, and large acreages are all factors that favor aerial applications. Generally, helicopters can carry eight to ten acres worth of material per load depending on the elevation. Fixed wing aircraft is only a possibility on very flat open ground. Where it can be used, it is more efficient than helicopter applications. Up to 50 acres per load can be applied with most fixed wing aircraft. The majority of the discussion here will concern helicopter treatments.

Targeting Vegetation with Aerial Applications

Developing prescriptions for aerial applications requires a good understanding of what can and can't be controlled by air. Since the quantity of material applied is less with aerial applications compared to hand treatments, the control of hard to kill brush species is more difficult by air. Herbaceous vegetation can be controlled equally as well by air or ground methods.

Herbaceous vegetation can be controlled with either foliar or soil active products. The difference is the duration of control. Any of the foliar chemicals such as glyphosate, triclopyr, 2,4-D, imazapyr, fluroxypyr or clopyralid will cause mortality of established herbaceous vegetation with aerial applications. With the exception of imazapyr, the other products have very little or no soil activity to prevent further germination. In this case herbaceous vegetation will rapidly re-occupy the site follow the application.

Using soil active products such as hexazinone, atrazine, sulfometuron methyl, oxyfluorfen or penoxsulam, the duration of control is extended by using chemicals that have residual activity in the soil. Hexazinone, atrazine, oxyfluorfen and penoxsulam have excellent conifer tolerance and can be applied as a pre or post plant application. Conifer tolerance issues with sulfometuron methyl prevent it from being used in the interior part of California, but applications on Coastal sites in the redwood range are possible. Hexazinone has the best knock down of emerged herbaceous vegetation. Atrazine and oxyfluorfen plus penoxsulam are best suited to pre-emergent applications unless another herbicide can be added. Knock down of existing herbaceous vegetation with oxyfluorfen plus penoxsulam is better than atrazine and can be improved with the addition of a methylated seed oil adjuvant.

Control of brush with aerial applications is a little more difficult. The size and type of brush, product and rate, timing, and adjuvant have major influences on control. Deciduous brush such as deerbrush (*Ceanothus integerrimus*) and snow berry (*Symphoricarpos albus laevigatus*) are fairly easy to control with applications of glyphosate. As deerbrush gets larger, control gets more difficult by air. This is true for most woody brush. Deciduous hardwood sprouts also prove difficult to control by aerial methods. They use of imazapyr alone or in combination with glyphosate dramatically improves control of larger woody deciduous brush and the addition of methylated or ethylated seed oils improves control further. Late summer timings of this treatment are usually better than earlier scheduling due to carbohydrate movement down into the root system later in the season. Due to conifer tolerance issues with imazapyr, only pre-plant applications are possible the year prior to planting, and seedlings still may show some symptoms of imazapyr damage. Deciduous brush and hardwood sprouts should usually not be treated with growth regulator products such as 2,4-D or triclopyr by air. These growth regulators cause rapid brownout of deciduous foliage and heavy damage to the translocating tissue in the plant. The result is rapid re-sprouting. Deciduous woody brush and hardwood sprouts treated in this manner, usually require re-treatment with a different method and product to achieve satisfactory control.

Evergreen brush such as tan oak (*Lithocarpus densiflorus*), golden chinquapin (*Chrysolepis chrysophylla*), greenleaf and whiteleaf manzanita (*Arctostaphyllos patula & viscida*, respectively), whitethorn (*Ceanothus cordulatus*) and snowbrush (*Ceanothus velutinus*) can be very difficult to control by air. Again, small plants are much easier to control by air than larger ones. Best control of evergreen brush is usually achieved with the oil soluble formulation of imazapyr (Chopper or Polaris AC) alone or in combination with glyphosate plus a methylated seed oil (MSO). These two systemic herbicides work incredibly well in combination. Both are ALS inhibitors, but they each inhibit three different amino acids

(Ahrens 1994). Imazapyr inhibits valine, leucine and isoleucine, while glyphosate keeps the plants from producing tyrosine, tryptophan and phenylalanine. They both translocate very well within the plant and do very little damage to the translocating tissue. Coverage is usually the critical factor when aerial applications are used. Evergreen brush is easily controlled with this herbicide mix with hand applications, aerial treatments are usually less so but still acceptable.

Triclopyr ester, fluroxypyr and/or 2,4-D ester can also be used on the evergreen brush species, but results are slightly less acceptable than the glyphosate plus imazapyr combination. Applications of fluroxypyr and 2,4-D ester plus an MSO do control manzanita species well. Timing of application with evergreen species is a little different than deciduous brush. Early summer timings usually provide the best control with either the glyphosate and imazapyr combinations or growth regulator applications of 2,4-D, fluroxypyr or triclopyr esters. When applying the ester formulations of 2,4-D and triclopyr, volatility will be an issue if temperature exceeds much over 75 degrees. If temperatures are warm, these products should not be used near neighbors or crops as off site damage may occur.

Aerial Project Planning

The first part of any helicopter program is planning. Foresters must evaluate each site on a unit by unit basis to determine what units can be applied by aerial methods and which ones are better suited to ground treatments, as well as what herbicide prescriptions are needed. Most units can be applied by air unless there are a large number of water courses, sensitive areas or neighbor issues that limit the amount of ground that can be treated with a helicopter. From a cost perspective, large steep units with poor access are ideal for helicopter applications since hand treatments would be extremely cost prohibitive.

During initial site visits, foresters need to define unit boundaries, look for suitable heliports, water sources, access, any potential hazards or sensitive areas that need mitigation, and staging areas. Unit boundaries need to be clearly defined and very obvious. Usually clear cut boundaries are defined by the edge of mature timber or roads. However, in many cases such as when dealing with large burns with multiple land-owners, this often isn't the case. Unit boundaries, property lines, exclusion areas, etc may be difficult to see, especially when different landowners have treated their ground relatively the same. Defining property and boundary lines as well as exclusion areas can be done in several ways. Painting large spots (at least two foot diameter) with bright marking paint on rocks, stumps or logs about every 50 feet works well, especially with blue marking paint since it shows up well from the air. Large reflective pieces of foil or very heavy high visibility flagging can also be used. Remember, the pilot is going to be flying 50 to 100 feet above the ground traveling at roughly 50 mile per hour.

Suitable heliports can be difficult to find. Large landings work well provided they do not have any obstructions such as larger trees, saplings or landing piles to hinder ingress and egress. Heliports should have at least two clear directions for takeoff and landings. Helicopters prefer to take off and land into the wind so it helps to have multiple options. Ideally, having some slope also helps so that the helicopter can drop off the heliport. The heliports also need to be smooth and level. They also cannot be so dusty that the pilot's vision is impaired, and treating them with water during dry conditions may be necessary. Good access to heliports is a must as the batch truck will need to be within about 50 feet of the helicopter to fuel and load is with the spray solution. The number of heliports needed for the project depends on the size and number of units. A one mile radius should be roughly the maximum distance flown from each heliport unless there are no other options. Ferrying long distances is extremely expensive to the contractor, and if there are no other options, that needs to be made clear in the contract negotiation as it will affect the cost.

Ideally, the easiest way to obtain water for mixing is from a mill site, log yard, office or other property under your control. Creeks may be used, provided the drafting equipment on the batch truck is equipped with anti-backflow devices to prevent contamination. It is prudent to avoid drafting from streams or ditches where domestic water is obtained. It is always a good idea to test water sources for pH and cat-ions if you are unfamiliar with the sources, as high cat-ion contents indicated by a high pH can tie up some active ingredients in solution, thus affecting efficacy. Never batch near your water source. Whenever possible, batching should be done on the spray site.

The most critical thing foresters need to locate and define are the areas within the spray project such as water courses, springs, wells, domestic ditches, lakes, ponds, property lines or other resources that need protection. Once located, they should be mapped and well defined on the ground so that the pilot is fully aware of their presence. Resources can be protected using the mitigation measures discussed earlier in this chapter.

If the project occurs near residences or other neighboring land owners, it is a good idea to make contact with them ahead of time. A written neighbor notification program is a valuable tool for training foresters and improving their ability to communicate what you are trying to accomplish and addressing any concerns they may have. Many problems can be avoided through good communication. Showing up unannounced at their doorstep with a helicopter first thing in the morning is not the way to meet your neighbors.

Roads are the one aspect of a spray operation that is often over looked. All roads accessing the project area need to be driven before spraying operations occur. Roads need to be cleared of debris and have to be passable for a 4,000 gallon batch truck. Water bars need to be lowered or removed if present, and any rolling dips or other drainage structures need to be passable. Helicopter time and auxiliary equipment are extremely expensive, and unexpected delays can't be tolerated.

A secure area needs to be established for a staging area where the helicopter and batch truck can be located when not spraying. The area should be where the spray equipment can be watched or in an area where access is restricted to company personnel.

It is also very important for the forester to have chemical for the project delivered ahead of time to avoid potential delays. In favorable conditions, helicopters can apply as much as 600 acres in a day. Transportation and storage of chemical also needs to be addressed before the project starts. The storage area needs to be a locked secure placarded area. Any opportunity to minimize the distance to haul chemical to the project should be encouraged.

Accurate mapping is a necessity. Global positioning systems (GPS) and geographic information systems (GIS) should be used in conjunction as much as possible. Unit boundaries, roads, stream courses, protected areas and property lines should all be accurately mapped using GPS and downloaded directly into the GIS. Most helicopters today come equipped with some type of GPS guidance system. Shape files for layers from the land owners GIS system (unit boundaries, roads, stream courses, lakes, ponds, ditches, property lines) can be downloaded directly into the helicopters GPS system. The GPS system not only shows the pilot an accurate map of all the layers in the system, but maps the spray swaths and helicopter position as the application occurs. This provides a very nice, mapped record of what was and wasn't sprayed, including aerial buffers, exclusion areas and the unit itself.

Spray contracts need to be prepared and contain all the necessary information and instructions to complete a successful project. Contracts should include a unit summary and treatment list, price per acre or other unit, project maps, application parameters, acceptable weather conditions, weather and application record keeping requirements and forms, licensing requirements, mitigation measures to follow, production schedules, chemical handling and transportation procedures, use reporting guidelines, container disposal guidelines and any other pertinent guidelines or information.

Aerial Project Implementation

When the aerial project is ready to begin, there are several things to consider. It is very helpful and wise to have two to three people working with the forester in charge of the project in the field. These extra people can be used to check weather conditions on units in advance of spraying, make sure units are clear of people, block access into the spray area, lead equipment in and out of spray units and keep weather records. By knowing what the weather conditions are on units yet to be sprayed, the project manager can efficiently move from one spray area to the next, saving valuable time and money.

When the helicopter arrives, it is pertinent to go over the spray plans, herbicide mixes, application volumes, mitigation measures, policies and calibration with the pilot and batch truck driver. Making sure the helicopter is calibrated prior to starting is critical to achieve the desired application rates. For reference on aerial calibration see Dreistadt (2013). Check the nozzle setup on the helicopter and make sure it is acceptable for your objectives. Based on the contract specifications, the helicopter should be set up the way you want it, but don't take it for granted.

Batching should be done on the spray unit at the start of each day to minimize traveling with a load of chemical in the batch truck. By batching on the unit, this also gives you an opportunity to assess weather conditions and batch the amount for what you think you can easily finish. When possible, it's best to avoid letting chemical sit over night in the spray tank. This will reduce problems with settling in the tank and potential vandalism issues.

Determining where to start your project may not make a difference much of the year, but occasionally in the fall with large projects bad weather can influence your program. In this case it is usually a good idea to start in the highest elevations first and work down in case snow becomes an issue. The opposite is true with large projects in the spring. Working from low to high usually makes the most sense as snow melts. One of the important things foresters will learn over time are the local weather patterns. This can save an inordinate amount of time and money figuring out where to start each day. Usually the wide temperature swings during the California day causes dramatic changes in wind patterns and direction. Before and after storm fronts pass through also bring in their own set of wind patterns. While all of this can effect spray operations, the patterns are fairly predictable.

Before starting to spray, the forester should recon the units with the pilot. The forester should show the pilot unit boundaries, water courses, property lines, sensitive areas, and anything else of concern. The forester can also give any special instructions such as when and where to utilize a split boom. The forester should also document the instructions given to the pilot in their daily spray records. Written notes are critical documentation in the event one ever gets taken to court over a spray application.

Finish spraying one unit before starting the next. As part of the forester's record keeping, each load and volume taken should be kept track of for each unit. It is imperative to know how much spray volume went on each unit. If the pilot is flying more than one unit at a time accurate records of how much volume went on each can not be kept. Keep in contact with the pilot during the application, but try and keep radio traffic to a minimum.

Be observant during the spray operation. Watch as creeks and drainages are flown to assure proper buffering is done and split boom applications are used. Make sure all the nozzles on the boom are working. Keep a watchful eye out for people or vehicles entering the spray area.

Accurate record keeping is invaluable. It allows you to keep track of the herbicide volume used, time, rates, mitigation measures used, costs, weather conditions and personnel. At a minimum, the forester should have two data sheets for record keeping. One for weather and one for each units spray record. At a minimum, the weather should be taken at least every hour, if not more and include time, wind speed and direction, temperature and humidity. The pilot is required to have weather records under California law. The unit summary data should include the unit name or number, acres, personnel present, contractor, herbicides used and rates applied, volume per acre, mitigation measures used, number of loads flown, volume used per load, total gallons flown, the time each load was flown, pilot name, and any other application notes pertinent to the job.

Hand Applications

A very expensive part of any reforestation effort is the labor cost of hand spraying. There are many application techniques and types of equipment that will help improve efficiencies and reduce costs. Making effective and efficient applications by hand is an art. As a result, hand spray labor is a very important area for a reforestation forester to focus their effort on when it comes to reducing costs. The more intimately familiar the forester becomes with the tools and techniques to operate efficiently and effectively, the more valuable the forester will be.

Having the Right Equipment

Usually hand spray crews are made up of 10 to 14 people. Any time the crew is waiting around and not spraying is extremely costly. Efficient application equipment should be built around the concept of reducing that time. If a crew has to spend much time waiting around for more water, or walking back to the batch truck to fill up their backpacks, costs can skyrocket.

The batch truck and associated equipment are the key to reducing costs in the field. Batch trucks should be set up with a spray tank large enough to carry a good supply of chemical. Five hundred gallon tanks are a good size. One of the real keys to reducing down time is to have a good supply of water. A water tender trailer is essential to reduce application costs. To work with the batch truck, a trailer fitted with at least a 750 gallon tank for water only is generally enough to supply a crew for an entire day. The water trailer should also be fitted with lockable metal storage bins to carry chemical, drafting equipment and other spray equipment. Drafting equipment should be kept in a separate storage container that is chemical free. Never put contaminated equipment into a water source to draft from. Storage containers need to be large enough to carry several 30 gallon containers of chemical. Having enough chemical on board to last several days will also help reduce costs dramatically.

Reducing the amount of time a crew spends walking without spraying is the key to reducing costs. Often times, reforestation units are large and when crews run out of spray solution in their backpacks, the time required to walk back to the batch truck to fill up can be substantial. Any efficient spray operation should have batch trucks set up with a power take off driven hose reel and pump system to bring the chemical to the crew instead of the crew to the chemical. A hose reel capable of holding at least 1200 to 1500 feet of high pressure hose and having the ability to pump uphill as well as down can save large amounts of time that would otherwise be spent walking. The hose reel itself needs to be set up with a power reel up system as hose with a full load of chemical can be extremely heavy. Usually hydraulic powered systems are best.

Good communication between the crew foreman and the batch truck driver is essential. Each should have a portable radio that the foreman can use to tell the batch truck where to move the truck to and when to pull or reel up the hose lay. This will also save a substantial amount of time.

In certain instances such as large wildfires with poor access it helps to have an off road vehicle equipped with a spray tank and delivery system to fill backpacks in the field. In remote areas where hose reels can not supply enough hose to reach the crew, an off road vehicle may provide an efficient alternative.

Managing access to units is critical. Too often roads that provide access to reforestation units are decommissioned immediately after logging operations cease. It is imperative to communicate with logging managers and plan writers the importance of leaving access to units open at least until the reforestation efforts are finished, which may be several years. Poor access will affect the cost of all reforestation activities, not just spraying.

Spray crews must be supplied with a wide variety of application equipment to achieve the desired objectives of the forester. Besides the standard backpacks and spray wands, crews should be trained and have the equipment to do broadcast, spot-gun, gun-jet and hack and squirt applications. A supply of meter jets, gun-jets, hatchets, and backpack injectors should be available. Having an extensive selection of nozzles including flat fans, off center and adjustable tip nozzles will also allow for a wide flexibility in the types of applications crews can do.

Directed Hand Spray Applications

Hand applications can consist of two types, broadcast applications where 100 percent of the ground area is treated at a specific rate per acre or some type of individual plant treatment. The first type of individual plant treatment discussed will be directed spray applications. This is the most common type of application used to control difficult woody brush. With this treatment individual plants are sprayed with a standard backpack and wand usually equipped with a flat fan nozzle. Nozzle types and characteristics are discussed in detail earlier in this chapter. The larger the orifice and angle of flat fan nozzles, the larger the drop size and wider the swath, respectively. Narrower angle nozzles give the applicator more control over what plants are covered. Occasionally, adjustable tip nozzles can be used for taller brush such as hardwood sprouts which allows the applicator to reach up higher on the plant.

Directed spray applications are used when the herbicide cannot be applied over the top of existing conifer seedlings without injury. In these types of applications, protection of the seedlings is necessary to prevent damage. Usually some type of shield with a handle is carried by each applicator. Seedlings are covered with the shield while the applicator sprays the vegetation around the tree, avoiding any contact.

With directed spray applications, it is very important to know what the target volume per acre should be. There are two reasons for this. The first is that you want to make sure that maximum label rates are not exceeded. Second, as volume per acre increases, crews slow down and hence, costs increase. By observing the crew spray a small known acreage at the beginning of the project, the forester can determine the volume per acre and adjust accordingly. It is a good idea to observe the spray pattern so the forester can tell by looking in the future whether crews are applying too heavy or too light. With directed applications, the use of dye is required to see what has and hasn't been sprayed.

Directed spray applications are usually batched on a percent solution basis. When that is the case, the forester needs to convert from percent solution to a rate per acre to determine if the application is being applied within the designated prescription rates. For example, if the maximum rate per acre of a given herbicide was one quart per acre and the crew was applying the mix at a 25 gallon per acre spray volume, the percent solution rate could not exceed one percent to avoid going over the maximum label rate. To adjust the volume per acre, nozzle size could be adjusted or the crew members could adjust the volume they are putting on each plant.

When planning directed spray projects, keeping costs to a minimum is essential. The smaller the brush, the less volume that is going to be applied and the cheaper it will be for labor and chemical. The crown volume of woody brush grows at an exponential rate from year to year. By delaying spray projects until brush gets large and dense, application costs can easily reach several hundred dollars per acre in just labor. Small seedling brush can be more easily controlled at a lower labor cost and a lower volume of herbicide applied. However, foresters need to be careful not to treat woody brush that has sprouted from old root systems too early before the plants have been able to put on enough crown to absorb enough chemical to control the existing root system.

Herbaceous vegetation treatments are usually not done using directed spraying with one exception. Occasionally landowners may want to apply glyphosate as a foliar treatment post-planting to control herbaceous vegetation. In this case, the glyphosate must be applied as a directed treatment since freshly planted conifer seedlings are not tolerant to over the top applications. Since there is no soil residual activity, residual weed seeds will not be controlled if the application is made before they have germinated. Likewise, if the application is made after the germinated plants have set seed, the new seed will then be present to germinate in subsequent growing seasons. For these reasons, the control of herbaceous vegetation using glyphosate needs to be critically considered and carefully timed. Longer lasting herbaceous treatments can be applied as a broadcast treatment with hexazinone, atrazine, sulfometuron methyl, or oxyfluorfen plus penoxsulam either as a pre or post plant application, unless conifer tolerance or company directives dictate otherwise.

Directed spray treatments can be used very effectively around sensitive areas such as water courses, lakes, ponds, property lines and other sites needing protection. Herbicides can be placed very accurately with this method with very minimal risk of off-site movement.

Broadcast Hand Treatments

The most efficient delivery method for herbicides by hand is applying them as a broadcast treatment, similar to a helicopter application. With broadcast applications, 100 percent of the ground area is treated in a systematic calibrated fashion. Depending on the conifer tolerance of the herbicide used, broadcast treatments may be applied pre or post plant. Broadcast applications are the most cost effective application method by hand. Depending on the type of equipment used, application costs can come close to that of a helicopter.

There are several methods that can be used to apply broadcast treatments. Boom spraying is a possibility, but not very practical with a large crew and requires a larger volume of spray solution than an individual can usually carry to be cost effective. Therefore, we will not discuss it here.

Most of the broadcast treatments are applied with what is known as the waving wand technique (Newton 2009). The technique can use either a conventional spray wand or a gun-jet application system. The wand is waved side to side at moderate speed so that the stream from the nozzle overlaps creating a solid swath as the applicator moves forward. To apply this method properly, the applicator must know the width of the swath they are producing, wave rapidly enough that coverage is solid, and calibrate the walking speed to achieve a target volume per acre.

The crew must be calibrated prior to making the application. To calibrate the waving wand method, first stand in one spot and spray, waving back and forth until the effective swath is visible on the ground. Measure the effective swath width. Then take a measured amount of water (one gallon) and put it in the backpack. Walk at a comfortable pace that can be maintained across an entire spray unit. Spray out the one gallon of water walking at the chosen pace waving the wand back and forth exactly as it was done to measure the swath with. Measure the distance traveled from where spraying started to when the backpack ran out of water. Calculate the area covered in square feet (swath width (ft) x distance traveled (ft)). Divide that number by 43,560 (square feet in an acre) to get the percentage of an acre sprayed. Divide the percentage of an acre sprayed into the volume sprayed out (in this example one gallon). That will tell you how many gallons per acre of spray solution you put out at that walking speed. That walking speed and waving technique must be replicated by all of the crew members and they must be spaced apart evenly so as to not overlap swaths too much or too little. Not being properly calibrated or trained in the application procedures can result in the wrong rates being applied, conifer injury or excessive skips left across the spray unit. This method is highly effective and efficient, but should only be applied by a properly trained and very experienced crew.

It is important to distinguish the difference between volume of solution applied per acre and the rate per acre of whatever herbicide you are using. In general, five to ten gallons per acre is the normal volume of solution applied (water and chemical) with waving wand applications depending on the method used. The rate per acre of herbicide is designated separately. For example, you can apply two quarts per acre of a glyphosate product in either five or ten gallons per acre of total solution. The two quart glyphosate would remain the same, but the dilution would change.

Several types of application setups can be used. For maximum production, gun-jet applicators can be used. This wand looks much different than a typical backpack wand and uses a disc nozzle similar to what is used in helicopter applications. The gun-jets have an adjustment where the spray output can be set at a straight stream down to a fine mist. The proper setting is to open the nozzle all the way so that it emits a straight stream and then begin to close it down to the point where the stream is just starting to become fractured. When waved side to side, swath widths of up to 30 feet can be achieved. Care must be taken to point the gun-jet away from the applicator as they walk so that they are not walking into the spray material. The gun-jet system is more suited for soil active herbicides as coverage is slightly variable. It is also highly sensitive to wind and worker exposure can be an issue if not properly applied. Adjustable tip nozzles can also be used with a normal spray wand that simulates a gun-jet application, but production and swath width are slightly less. This method is slightly slower, but is a little more forgiving regarding working exposure and drift.

The most effective and controllable waving wand application method is the off center nozzle system. In this case, a normal spray wand is utilized, but fitted with an off center nozzle (OC nozzle). This nozzle puts out an elongated spray pattern that when waved side to side provides superior coverage over any other waving wand method. It is also the method with the least applicator exposure, as the nozzle spray pattern is pointed downward and thrown away from the applicator as it is applied. This method can be used for either foliar or soil active products. Smaller orifice off center nozzles should be utilized for foliar applications for better coverage. Swath widths are reduced to about 12 to 15 feet with off center nozzles compared to the gun-jet system, but production rates are only slightly less. Swath width and walking speed increase as the size of the nozzle orifice increases. Hence, application costs are reduced with increasing nozzle size.

Topography can severely affect the pace of the spray crew when doing waving wand applications. Inherently, crews slow down on steep slopes or in units with heavy slash loads. The forester and foreman need to be aware of changing conditions that may affect the volume per acre applied. Changing nozzle size is a good way to deal with changes in topography. Using smaller nozzles on steeper slopes or units with heavy slash will adjust for a slower walking pace and maintain the same volume per acre used on easier ground.

One other limitation of the waving wand method is the height and density of brush. When brush gets more than about three or four feet tall and dense, waving the wand gets exceedingly difficult. Pace is more difficult to maintain, as is keeping the crew members together. To do these applications effectively, crew members need to stay together and keep in an organized line so that each one can see where the next has sprayed. The last applicator in line or the foreman, needs to flag the outside spray line so the crew knows where to follow back on when they turn around to make another pass.

A well trained crew in broadcast application techniques is an invaluable asset to a reforestation forester. Application costs can range as low as 25 to 45 dollars per acre for labor depending on the application and site. This is not the application type that you want to contract out as a low bid application. Broadcast applications by hand are very complicated and results can be poor if not applied properly. Foresters need to be aware that crews can cover a large amount of acreage in one day, and if not applied properly, the results could be very costly.

Hack and Squirt Applications

Hardwood trees and sprout clumps are extremely competitive to young conifer seedlings in California (Jackson & Lemon 1988). Sprouting hardwoods from cut stumps can occupy large areas within a reforestation unit in a very short amount of time, depriving seedlings of valuable light, nutrients and water

(DiTomaso, Keyser & Fredrickson 2004). Where hardwood populations are heavy, reforestation units could be entirely dominated by hardwood cover if not managed to some degree. It is wise to designate a certain number of hardwood trees and clumps for retention for wildlife concerns, but if left totally unmanaged this can cause significant problems for reforestation efforts.

Hack and squirt applications are one of the most important techniques we have for managing hardwoods. It is a very selective technique that allows for managing hardwoods at whatever density the land manager chooses. It is a fairly simple but extremely efficacious, efficient and cost effective treatment.

The tools required are a hatchet, a small gravity fed backpack and a calibrated veterinary syringe capable of delivering a specific amount of liquid (Figure 8.4). The veterinary syringe can be set to a specific amount of chemical to inject. In most cases the delivery amount is set at either one half or one full milliliter of liquid. The number of hacks made per tree is determined by using either a specific spacing around the circumference of the tree or designating one hack for every so many inches of tree diameter at breast height (Figure 8.5). For example, using circumference, a hack could be placed every six inches around the circumference of the tree. When using diameter as a guide, a tree could be injected using one hack per every three inches of diameter at breast height. In this case a 9 inch tree would receive three hacks. Once hacked, the appropriate amount of chemical would be injected into each hack using the veterinary syringe. The chemical is usually used undiluted.

In the case of treating hardwood clump sprouts where the stems are too small to hack on a circumference or diameter basis, the number of injections is usually determined by selecting a certain number of stems to inject per clump. Stems may either be hacked with a hatchet if large enough or snapped by hand and the chemical injected into the broken stem.

Trees and clump sprouts can be injected almost all year long, however spring treatments are not recommended when sap is flowing. At that time, chemical injected into the cuts can be pushed out of the hack area to the extent that it makes the treatment ineffective. Big leaf maple will begin flowing sap as early as late January in northern California. The most effective timing is usually late summer through the entire winter for most hardwoods (Ditomaso, Keyser & Fredrickson 2004).

The most widely used herbicide for injection treatments is imazapyr, and it is without a doubt the most effective. Conifer tolerance precludes its use as a release treatment in many situations, but it is ideal as a treatment for pre-harvest site preparation or pre-plant site preparation which will be discussed later in this chapter. It is important to realize that imazapyr does have soil activity and translocates very well with plant systems. Many hardwood species that are growing in close proximity to one another are known to form root grafts. Any tree that is root grafted to a treated tree may show visible symptoms or even death.

This is an important consideration when treating near property lines. Buffer zones may be needed to prevent inadvertent mortality across property lines or to trees intended to be retained for wildlife features (Ditomaso, Keyser & Fredrickson 2004). Imazapyr may also be exuded through the roots of treated trees into the soil where conifer seedlings could absorb it and be damaged.

One of the benefits of having a hack and squirt program is that crews can operate when windy or other weather precludes them from foliar spraying. The only weather condition that will prohibit hack and squirt applications is heavy rain as freshly injected chemical may be washed out of the cuts. Planning the total application program with the option of utilizing the crew for hacking when weather prohibits other application methods will provide a more consistent supply of work.

Application costs depend on the density and type of hardwood treatment. Labor costs with tree hack and squirt in the interior part of California in typical black oak (*Quercus kelloggii*) stands usually averages somewhere between 20 and 50 dollars per acre. Hack and squirt treatments on the Coast of California can be much higher due to heavy densities of tan oak (*Lithocarpus densiflorus*), as can stands with dense under-stories of other hardwood sprouts. Herbicide rate per acres needs to be closely monitored in stands that have very high stem densities as the maximum rate per acre could easily be exceeded.

Treating hardwoods prior to planting is much preferable than post-plant treatments. Benefits usually include lower costs, better conifer tolerance and better efficacy.

Cut Stump Treatments

Cut stump treatments are seldom utilized in forestry due to cost and the ability to use other more efficient and effective methods. Trees or brush can be treated with this method. Plants are treated by severing the stem or bole with a chainsaw or other cutting tool and then using a squirt bottle to apply either a high concentration solution or undiluted herbicide around the cambium of the stump. Herbicide need not be applied to the deadwood in the center of the stump. The key to applying cut stem treatments is to treat the stumps immediately after cutting because delaying the application will dramatically reduce translocation and efficacy.

Several herbicides can be used with cut stump applications. Triclopyr, glyphosate and imazapyr are the three that are most commonly used. It is imperative with triclopyr in warm weather to make sure that the amine formulation is used as the ester formulation will volatilize. Care must be taken with imazapyr if stumps are treated along property lines or right of ways where adjacent vegetation may be root grafted to treated stems. Cut stump applications are generally most effective in the late summer to winter, but may be treated most times of the year other than during spring sap flow.

The major deterrent to cut stump treatments is the labor cost associated with cutting of the vegetation. Chainsaw removal of large brush may cost as much as 300 to 400 dollars per acre in dense stands. These treatments are often used when brush is too tall to foliar spray but the land manager wants to treat the vegetation before clearing the ground for planting to avoid

re-sprouting. In the instance where vegetation is so large that it can not be foliar treated before mechanical site preparation activities occur, it may be more cost effective to pile the vegetation first and manage the re-sprouting vegetation. In general, it is best to treat the vegetation prior to removal to maximize efficacy and reduce costs.

Basal Bark Treatments

Basal bark treatments are used primarily to control re-spouting hardwoods and larger woody brush. The herbicide solution is applied to the bark of the lower stems of plant, near the ground line. Triclopyr ester and imazapyr are the main herbicides used with basal treatments. With basal applications, the herbicides are mixed with a basal bark oil as the carrier instead of water to get penetration through the bark. Bark thickness increases as plants get older and therefore, basal treatments are limited to stems with a maximum ground line diameter of three inches or less.

There are three types of basal bark applications - conventional, low volume and thin-line basal treatments. With convention basal treatments, stems of treated plants are sprayed around the entire circumference of each stem from the ground line up to a height between 18 and 24 inches depending on the preference of the land manager. It is very important to completely cover the circumference of every stem and to heavily cover the root collar area on the stump to insure control. Low volume basal treatments are applied in the same way, but the herbicide concentration is significantly higher than what is used with conventional basal treatments and the stems are only treated to a height of six inches above the ground line, reducing the total volume used.

Thin-line treatments are still applied to the base of the stems but in a much different way. Thin-line uses the highest concentration of solution of any of the methods, but also the lowest volume. The spray solution is applied through a nozzle that produces a straight stream. The stream is arced across the base of the stems from left to right to a height of about one foot above the ground line from three or four sides of the plant. The idea is to connect all of the arcs so that all stems receive some coverage. Unlike conventional or low volume basal treatments complete coverage around the entire circumference of the stem is not necessary due to the concentration of herbicide solution.

Labor costs are the most expensive for the conventional basal treatments followed by the low volume treatments, with thin-line treatments being the least expensive. The efficacy of basal bark treatments vary dramatically by geographic region. In the interior parts of California, basal treatments do not typically work as well as other treatments designed to treat hardwood sprouts such as foliar or hack and squirt treatments with imazapyr. Heavy re-sprouting usually occurs with basal applications on species like black oak (*Quercus Kellogii*) and dogwood (*Cornus nuttallii*). In Oregon, basal treatments with triclopyr ester are the most effective method on species such as tan oak and big leaf maple (*Acer macrophyllum*) (Gourley personal communication).

Spot-Gun or Meter-Jet Applications

Spot-gun and meter-jet applications are one and the same and will be referred to as spot-gun for the rest of this text. This is a very efficient application technique for controlling various types of woody vegetation that are sensitive to the herbicide hexazinone such as snowbrush (*Ceanothus velutinus*), whitethorn (*Ceanothus cordulatus*), deerbrush (*Ceanothus integerrimus*) or greenleaf manzanita (*Arctostaphyllos patula*). Spot-gun treatments are applied using a Meter-jet application system to individual plants or on a grid system if plant cover is too heavy to treat individual plants. The device delivers a measured amount of chemical with each pull of the trigger and can be adjusted to deliver a range of rates. The herbicide is applied undiluted to the soil about midway between the root collar and the branch tips. Generally, three milliliters of the liquid formulation of hexazinone per spot is applied. The number of spots a plant receives is dependant upon the size of the plant. Most plants receive a minimum of two spots. The spot where the herbicide is applied must be free of litter or other debris that may tie up the chemical.

This application system requires an experienced crew to properly apply the treatment. Crews must be careful not to exceed the maximum label rate. Crop trees may be damaged or killed if too much hexazinone is applied in any given area. If the vegetation is too heavy to treat individual plants and a grid system must be used, another treatment method should probably be considered as grid applications are not nearly as effective. Spot-gun applications are best suited to low brush densities. Conifers can also be severely injured or killed in stands adjacent to treated areas as root uptake occurs. Large cedars and sugar pines are at the highest risk in close proximity to the treatment area and may be killed if not given a large enough buffer. It is also important to adjust the spot placement when treating on steep slopes. Spots should be placed around the upper sides of the plant so the herbicide does not move down slope away from the root system.

Rainfall is required to activate the hexazinone. The majority of spot-gun applications are applied in the fall as the main target is snowbrush which occurs in the upper elevations. It is important not to get too much or too little precipitation for the herbicide to work correctly. Generally, between three and twenty inches of rain is desired for effective hexazinone applications. Lower elevation species such as deer brush could theoretically be treated in the spring if an adequate moisture window still exists. Spot-gun applications are highly effective and very efficient from an application standpoint. The cost per acre is generally very low and labor costs usually range between $25 and $35 per acre.

Tractor or ORV Applications

Opportunities to utilize tractor or ORV mounted spraying systems in forestry are minimal. Usually terrain, stumps, brush, rocks, snags and residual conifers prohibit efficient use of such systems. There are instances where it may be possible such as roadsides, pasture conversions or very flat and clean clear cuts relatively free of slash.

Where it is possible, the applications are similar to aerial traetments. They are primarily broadcast applications to be applied at a certain volume per acre with the potential exception of roadside applications. In this case, calibration of the system and traveling speed is critical (see Dreistadt 2013 for calibration of tractor mounted systems). The choice of herbicides used will depend largely on what vegetation is present on the site and whether or not conifer seedlings have been established. Pre or post plant applications can be made with a tractor or ORV system provided tree height and conifer tolerance is not an issue.

The delivery system for these applications is primarily through a mounted boom. For forestry applications shorter booms are better. Unique configurations of flood-jet and off-center nozzles could also be used to reduce boom lengths and increase the maneuverability in reforestation units. Roadside applications usually either have a hand-held nozzle system mounted to the spray or a half-boom with off-center or flood-jet nozzles to treat roadsides.

The main benefits of tractor or ORV mounted systems is control of the spray deposition. The spray solution can be accurately placed along stream buffers, property lines and other sensitive areas to make sure contamination does not occur. Application costs are relatively cheap and are along the lines of broadcast hand applications.

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References

Ahrens, W.H. Editor. 1994. Herbicide Handbook-7th Edition. Weed Science Society of America. Champaign, Il. 352 P.

Akesson, N.B., R.E. Cowden and W.E. Yates. 1985. Atomization of Herbicide Simulants with Hollow Cone and Raindrop Nozzles. USDA Forest Service. Forest Pest Management.
FPM 85-1. 103 P.

Akesson, N.B., W.E. Yates and S.E. Wilco. 1970. Key to safe and Effective Aerial Application: Controlling Spray Atomization. Agrichemical Age. December. Pp 10-17.

Allen, B.H. and J.W. Bartolome. 1989. Cattle Grazing Effects on Understory Cover and Tree Growth in Mixed Conifer Clearcuts. Northwest Science. 63(5): 214-219.

Ambach, N.H. and R. Ashfored. 1982. Effects of Variation in Drop Make-up on the Phytotoxicity of Glyphosate. Weed Science. 30:221-224.

Arno, S. F., M.G. Harrington, C.E. Fiedler and C.E. Carlson. 1996. Using Silviculture and Prescribed Fire to Reduce Fire Hazard and Improve Health in Ponderosa Pine Forests. Proc. 17th Ann. Forest Vegetation Management Conference. Redding, Ca pp. 114-118.

Babiker, A.G.T. and H.J. Duncan. 1974. Penetration of Bracken Fronds by Asulam as Influenced by the Addition of Surfactant to the Spray Solution and by pH. Weed Reasearch. 14: 375-377.

Barry, J. W. 1984. Drop Size: Drift and Effectiveness of Herbicide Sprays. Forest Vegetation Management Workshop. Oregon State University. July 17-19. pp 1-22.

Beaudry, P.G. 1990. Downslope Movement of the Herbicide Hexazinone in the SBS Zone. B.C. Ministry of Forests. December 1990.

Brevis, Juan C., T. Lanini, K. Giles, D.C. Slaughter, D. Downey and C. Gliever. 2004. Weed Control Using a Prescision Application System with Image Vision. Proc. Cal. Weed Sci. Soc. 56: 139-140.

Brewster, B.D. and A.P. Appleby. 1990. Effect of Rate, Carrier Volume, and Surfactant on Imazamethabenz Efficacy. Weed Technology. 4: 291-293.

Buhler, L. and O.C. Burnside. 1987. Effects of Application Variables on Glyphosate Phytotoxicity. Weed Technology. 1:14-17.

Busse, M.D., N.G. Rapaport, and R.F. Powers. 2000. Tolerance of Soil Organisms to Herbicide Applications in Ponderosa Pine Plantations. Proc. 21st Ann For. Veg. Mgt. Conf. Redding, Ca. pp 33-38.

Chandran, R.S. and L.W. Jett. 2009. Weed Management in Vegetables. West Virginia University Extension. Extension Bulletin. 2009.

Chase, C. A., J.M. Scholberg and G.E. MacDonald. 2004. Preliminary Evaluation of Nonsynthetic Herbicides for Weed Management in Organic Orange Production. Proc. Fla. State Hort. Soc. 117:135-138.

Coates, K.D., M.J. Douglas, J.W. Schwab and W.A. Bergerud. 1993. Grass and Legume Seeding on a Scarified Coastal Alluvial Site in Northwestern British Columbia: Response of Native Non-Crop Vegetation and Planted Sitka Sprice (Picea sitchensis(Bong.) Carr.) Seedlings. New Forests. 7:193-211.

Cole E.C. and M. Newton. 1989. Seasonal Efficacy Comparison of Two Glyphosate Formulations. Proc. Western Soc. Of Weed Sci. 42:136-141.

Craig, S. and J. McHenry. 1988. Mulch Collars for Preventing Vegetation Around Conifer Seedlings: A Test of Several Methods. Proc. 9th Ann For. Veg. Mgt. Conf. Redding, Ca. pp 142-150.

Crammer, J.R. and D.L. Lindscott. 1990. Droplet Make-up and the Effect on Phytotoxicity in Glyphosate. Weed Science. 38:406-410.

Curran, W.S., D.D. Lingenfelter and C.B. Muse. 2005. Effectiveness of Vinegar and Clove Oil for Control of Annual Weeds. Poster Session. Weed Science Society of America. 2005. 1 P.

D'Anjou, B. 1990. Growth Response of Several Vegetation Species to Herbicides and Manual Cutting Treatments in the Vancouver Forest Region. FRDA Report #135. B.C. Ministry of Forests. 6 P.

DiTomaso, J.M., G.B. Kyser and E.A. Fredrickson. 2004. Control of Black Oak and Tan Oak in the Sierra Nevada Range. W. Jor App. For. 19(4):268-276

Dreistadt, S.H. 2013. Forest and Right of Way Pest Control. Second Edition. University of California. ANR Pub 3336. 340 P.

Evans, Glenn J. and R.R. Bellinder. 2009. The Potential Use of Vinegar and a Clove Oil Herbicide for Weed Control on Sweet Corn, Potato and Onion. Weed Tech. 23(1): 120-128.

Fan, Z., J.A. Moore, B. Shafii and H.L. Osborne. 2002. Three Year Responses of Ponderosa Pine Seedlings to Controlled Release Fertilizer Applied at Planting. West. J. Appl. For. 17(3): 154-164.

Fiddler, G. O. and P.M. McDonald. 1997. Mechanical and Chemical Release Applied to a 12 Year Old Pine Plantation. USDA Forest Service. Pacific Southwest Forest and Range Experiment Station. Research Paper. PSW-RP-232. 12 P.

Fiddler, G. O. and P.M. McDonald. 1999. Treatment Duration and Time Since Disturbance Affect Vegetation Development in a Young Ponderosa Pine Plantation. USDA Forest Service. Pacific Southwest Research Station. Research Note. PSW-RN-424. 8 P.

Fiddler, G. O., P.M. McDonald and S.R. Mori. 2000. Mechanical and Chemical Release Applied to a 16 Year Old Pine Plantation. USDA Forest Service. Research Note. PSW-RN-425. 10 P.

Fisk, J.N. 1984. Estimating Effects of Competing Plants on Conifer Growth and Yield, and Determining Release Needs. Proc. 6th Ann. For. Veg. Mgt. Conf. Nov 1-2, Redding, Ca. pp. 129-143.

Fredrickson, E. A. 1994. Efficiency of Forest Vegetation Control with Herbicides. Oregon State University. M.S. Thesis. 204 P.

Fredrickson, E.A. and M. Newton. 1998. Maximizing Efficiency of Forest Herbicides in the Sierra Nevada and Oregon. User Guide. Corvallis, Or. Oregon State University. Research Contribution 19. 45 P.

Fredrickson, E.A. 2002. Fall Planting in Northern California. USDA Forest Service. Rocky Mountain Research Station. Proc. RMRS-P-28. pp 159-161.

Fredrickson, E.A. 2004. Pre-Harvest Site Preparation with Herbicides. Abstract. 25th Ann. For. Veg. Mgt. Conf. Redding, Ca. p. 79.

Fredrickson. E.A. 2005. The Influence of Initial Stock Size on Seedling Survival and Growth. Presentation for the 26th Ann. For. Veg. Mgt. Conf. Redding, Ca.

Fuller, J. L. 2002. Assessing the Safety of Biological Weed Control: A Case Study of the Cinnabar Moth. M.S. Thesis. Oregon State University. 59 P.

Fullmer, D.G. 1986. Sheep Grazing for Plantation Release: A Foresthill Ranger District Case Study. Proc. 8th Ann. Forest Vegetation Management Conference. Sacramento, Ca. pp. 149-163.

Gratkowski, H. and R. Stewart. 1973. Aerial Spray Adjuvants for Herbicide Drift Control. USDA Forest Service. Pacific Northwest Forest and Range Experiment Station. General Technical Report. PNW-3. 18 P.

Harper, G.J., P.G. Comeau and B.S. Biring. 2005. A Comparison of Herbicide and Mulch Mat Traetments for Reducing Grass, Herb and Shrub Competition in the BC Interior Douglas-Fir Zone-Ten Year Results. West. J. Appl. For. 20(3): 167-176.

Harrington, T. B. and S.D. Tesch. 1992. Manual Cutting In Forest Vegetation Management. Proc. Forest Vegetation Management Without Herbicides. Oregon State University. pp 112-117.

Haywood, J. D. 1999. Durability of Selected Mulches, Their Ability to Control Weeds, and Influence Growth of Loblolly Pine Seedlings. New Forests. 18: 263-276.

Haywood, J. D. 2000. Mulch and Hexazinone Herbicide Shorten the Time Longleaf Pine seedlings are in the Grass Stage and Increase Height Growth. New Forests. 19:279-290.

Helms, J.A., C. Hipkin, and E.B. Alexander. 1986. Effects of Soil Compaction on Height Growth of a California Ponderosa Pine Plantation. West. Jor. App. For. 1: 104-108.

Hess, D. and R.H. Faulk. 1990. Herbicide Deposition on Leaf Surfaces. Weed Science. 38:280-288.

Hollaway, J.K. 1964. Projects in Biological Control of Weeds. P. Debach editor. Biological Control of Insect Pests and Weeds. Reinhold Publishing Corp. New York. pp 650-670.

Hudson, B.D. 1994. Soil Organic Matter and Available Water Capacity. Jor. of Soil and Water Cons. 49(2): 189-194.

Isaacson, D. and M.H. Brooks. 1999. Weed Control: Extended Abstracts from the 1997 Interagency Noxious Weed Symposium. USDA Forest Service FHTET-98-12, June. 59 P.

Jackson, N.E. and M.D. Lemon. 1986. Timing of Application Studies with Roundup Herbicide for Control of Bear Clover (*Chamaebatia foliolosa*) in California Forestry. Proc. 8th Ann. For. Veg. Mgt. Conf. Nov 5-6. Sacramento, Ca. pp. 113-119.

Jackson, N.E. and M.D. Lemon. 1988. *Roundup herbicide for control of bear clover (Chamaebatia foliolosa) in California forestry*. Paper presented at the 8th Annual Forest Vegetation Management Conference.

Johnson, S.A. 1987. Pronone Herbicide: A Granular Hexazinone Formulation for Site Preparation and Conifer Release. Proc. 9th Ann. For. Veg. Mgt. Conf. Nov 3-5. Redding, Ca pp:34-42.

Kauffman, J.B. 1992. Prescribed Fire in Forest Vegetation Management: A Research Synthesis. Proc. Forest Vegetation Management Without Herbicides. Oregon State University. Corvallis, Or. Feb 18-19. pp 25-28.

Kelpas, B., & Landgren, C. (2018). Forestry and Hybrid Cottonwoods In E. Peachy (Ed.), *Pacific Northwest Weed Management Handbook [online] https://pnwhandbooks.org/weed* Corvallis, Oregon: Oregon State University.

Ketchum, J.S. and R. Rose. 2000. Interaction of Initial Seedling Size, Fertilization and Vegetation Control. Proc. 21st Ann. For. Veg. Mgt. Conf. Jan 18-20. Redding, Ca. pp 63-69.

Knowe, S. A. 1992. Manual Techniques for Managing Woody Competition: An Overview. Proc. Forest Vegetation Management Without Herbicides. Oregon State University. pp. 90-91.

Kruger, W.C. and M. Vavra. 1984. 20th Year Results from a Plantation Grazing Study. Oregon Agricultural Experiment Station. Special Report 715: 20-24.

McDonald, P., G.O. Fiddler, R.A. Tucker and A. Colaninno. 1989. Manual Release in an Old Douglas-Fir Plantation Increases Diameter Growth. USDA Forest Service. Research Note. PSW-405. 3 P.

McDonald, P. and G.O. Fiddler. 1990. Ponderosa Pine Seedlings and Competing Vegetation: Ecology, Growth and Cost. USDA Forest Service. Research Paper. PSW-199. 10 P.

McDonald, P.M. and G.O. Fiddler. 1992. Mulching and Grubbing Techniques in Forest Vegetation Management: A Research Synthesis. Proceedings of a Workshop on Vegetation Management without Herbicides. Oregon State University. Corvallis, Or. Feb 18-19. pp 92-98.

McDonald, P. M. and G.O. Fiddler. 1993. Vegetative Trends in a Young Conifer Plantation After Ten Years of Grazing by Sheep. USDA Forest Service. Research Paper. PSW-RP-215. 9P.

McDonald, P. M., G.O. Fiddler and W.T. Henry. 1994. Large Mulches and Manual Release Enhance Growth of Ponderosa Pine Seedlings. New Forests. 8:169-178.

McDonald, P.M. and G.A. Everest. 1996. Response of Young Ponderosa Pines, Shrubs and Grasses to Two Release Treatments. USDA Forest Service. Pacific Southwest Research Station. Research Note. PSW-RN-419. 8 P.

McDonald, P.M. and C.S. Abbott. 1997. Vegetation Trends in a 31-Year-Old Ponderosa Pine Plantation: Effect of Different Shrub Densities. USDA Forest Service. Pacific Southwest Forest and Range Experiment Station. Research paper PSW-RP-231.

McDonald, P. and G.O. Fiddler. 1999. Recovery of Bear Clover (Chamaebatia foliolosa) Plant Community After Site Preparation and Planting of Ponderosa Pine Seedlings. USDA Forest Service. Research Note. PSW-RN-423. 7 P.

McDonald, P.M. and G.O. Fiddler. 2001. Timing and Duration of Release Treatments Affect Vegetation Development in a Young California White Fir Plantation. USDA Forest Service. Pacific Southwest Forest and Range Experiment Station. Research paper PSW-RP-246.

McDonald, P. and G.O. Fiddler. 2007. Development of Vegetation in a Young Ponderosa Pine Plantation: Effect of Treatment Duration and Time Since Disturbance. USDA Forest Service. Research Paper. PSW-RP-251. 23 P.

McHenry, W.B., A. Scarlett, T.F. Robson and L. Lindstrand Jr. 1982. Chemical and Mechanical Grass Control. Proc. 4th Ann. Forest Vegetation Management Conference. Eureka, Ca. pp.47-55.

Milliman, L.J. 1999. Effects of Sheep Grazing to Control Weeds in a Pine Plantation on Weed Reproductive Success, Trees and Sheep Performance. M.S. Thesis. Oregon State Univiersity. 82 P.

Moran, P.J. and S.M. Greenberg. 2006. Winter Cover Crops and Vinegar as Weed Control Techniques in Sustainable Cotton production. Proc. National Cotton Council Beltwide Cotton Conference. San Antonio, Tx. pp. 2188-2195.

Neary, D.G., P.B. Bush and J.E. Douglas. 1983. Off-site Movement of Hexazinone in Stormflow and Baseflow from Forest Watersheds. Weed Science. 31: 543-551.

Newton, M. and F.N. Dost. 1984. Biological and Physical Effects of Forest Vegetation Management. Final Report, Washington Department of Natural Resources. 423 P.

Newton, Michael and D.S. Preest. 1988. Growth and Water Relations of Douglas-Fir (Pseudotsuga menziezii) Seedlings Under Different Weed Control Regimes. Weed Science. 36: 653-662.

Newton, M. and E.C. Cole. 1993. Tall Planting Stock for Enhanced Growth and Domination of Brush in the Douglas-Fir Region. New Forests. 7:107-121.

Oester, P. T., W. Emmingham, P. Larson and S. Clements. 1995. Performance of Ponderosa Pine Seedlings Under Four Herbicide Regimes in Northeast Oregon. New Forests. 10:123-131.

Oliver, W.W. 1984. Brush Reduces Growth of Thinned Ponderosa Pine in Northern California. USDA Forest Service. Pacific Southwest Forest and Range Experiment Station. Research paper PSW-172.

O'Sullivan, P.A., J.T. O'Donovan, and W.M. Hamman. 1981. Influence of Non-ionic Surfactants, Ammonium Sulphate, Water Quality and Spray Volume on the Phytotoxicity of Glyphosate. Can. Jor. of Plant Sci. 61: 391-400.

Owen, M. D. 2002. Acetic Acid (Vinegar) for Weed Control Revisited. Extension Bulletin. Iowa State University. July 8, 2002.

Paley, S.M. and S.R. Radosevich. 1984. Effect of Physiological Status and Growth of Ponderosa Pine (Pinus ponderosa) and Greenleaf Manzanita (Arctostaphylos patula) on Herbicide Selectivity. Weed Sci. 32:395-402.

Pendl, F. and B. D'Anjou. 1990. Effect of Manual Treatment Timing on Red Alder Regrowth and Conifer Response. FRDA Report #112. B.C. Ministry of Forests. 14 P.

Peterson, T.D., M. Newton and S.M. Zedaker. 1988. Influence of Ceonothus Velutinus and Associated Forbs o the Water Stress and Stemwood Production of Douglas-Fir. For. Sci. 34(2): 333-343.

Pitcairn, Michael, J. 1999. Advancements in Biological Control of Weed Species Via Insects and Fungi. Proc. 20th Annual Forest Vegetation Management Conference, Redding, Ca. pp. 60-63.

Potter, D.A. 1984. Control of Bear Clover. Proc. 6th Ann. For. Veg. Mgt. Conf. Nov 1-2. Redding, Ca. pp 144-150.

Powell, R. L. 1992. Prescribed Fire for Conifer Regeneration in the Oregon Coast Range. Proc. Forest Vegetation Management without Herbicides. Oregon State University, Feb 18-19. pp.33-38.

Powers, R.F. and G.O. Fiddler. 1997. The North American Long-Term Soil Productivity Study: Progress Through the First Five Years. Proc. 18th Ann. For. Veg. Mgt. Conf. Jan 13-16. Redding, Ca. pp 88-102.

Powers, R. F. and P.E. Reynolds. 1999. Ten Year Responses of Ponderosa Pine Plantations to Repeated Vegetation and Nutrient Control Along an Environmental Gradient. Can. Jor. For. Res. 29: 1027-1038.

Radosevich, S.R., E.J. Ronconi, S.G. Conard, and W.B. McHenry. 1984. Seasonal Tolerance of Six Coniferous Species to Eight Foliage-Active Herbicides. Forest Science. 26:3-9.

Radosevich, S.R. 1984. Interference Between Greenleaf Manzanita (*Arctostaphylos patula*) and Ponderosa Pine (*Pinus ponderosa*). Seedling Physiology and Reforestation Success. Duryea, M.L. and Brown, G.N. editors. Martinus Nijhoff and Dr. W. Junk publishers. Boston. pp 259-270.

Rhodes, R.C. 1980. Studies with C14-Labeled Hexazinone in Water and Bluegill Sunfish. Agricultural and Food Chemistry. 28(2): 306.

Rose, R. and S.J. Ketchum. 2002. Interaction of Vegetation Control and Fertilization on Conifer Species Across the Pacific Northwest. Can. J. For. Res. 32:1-17.

Sharrow, S.H. 1992. Animal Grazing in Forest Vegetation Management: A Research Synthesis. Proc. Forest Vegetation Management Without Herbicides. Oregon State University. pp.53-60.

Simard, S. and J. Heineman. 1996. Nine Year Response of Douglas-Fir and the Mixed Hardwood-Shrub Complex to Chemical and Manual Release Treatments on an ICHmw2 Site Near Salmon Arm. FRDA Report #257. B.C. Ministry of Forests. 15 P.

Sparks, B.D., A. Sundaram, L. Kotlyar, J.W. Leung and R.D. Curry. 1988. Physiochemical Properties Deposition Pattern of Some Newtonian Spray Mixtures of Glyphosate Containing Two Spray Modifier Adjuvants. Jor. Env. Sci. Health. B23(3): 235-266.

South, D.B., J.L. Rakestraw and G.A. Lowerts. 2001. Early Gains from Planting Large Diameter Seedlings and Intensive Management are Additive for Loblolly Pine. New Forests. 22:97-110.

Steen, Ordell and A. Smith. 1991. Grass and Legume Seeding for Vegetation Control on Blade Scarified Sites in the ICH and ESSF Zones in the Central Interior of British Columbia. FRDA Report #182. B.C. Ministry of Forests. 23 P.

Stevens, P. J. G. and J. A. Zabkiewicz. 1990. New Formulation Technology-Silwet Organosilicone Surfactants have Physical and Physiological Properties which Enhance the Performance of Sprays.

Proc. 9th Australian Weed Conference. Editor J.W. Heep. August 6-10. Adelaide Convention Center. Adelaide, South Australia. pp 327-331

Sundaram, A. 1990 (a). Effect of Nalcotrol 11 on Bioavailability of Glyphosate in Lab Trials. Jor. of Env. Sci. Health B 22(3): 319-346.

Sundaram, A. 1990 (b). Influence of Two Polymeric Adjuvants on Physical Properties, Droplet Spreading and Drying Rates, and Foliar Uptake and Translocation of Glyphosate in Vision Formulation. ASTMSTP 1086. American Society for Testing and Materials

Tappenier, J.C. and S.R. Radosvich. 1982. Effect of Bearmat (*Chamaibatia foliolosa*) on Soil Moisture and Ponderosa Pine (Pinus ponderosa) Growth. Weed Science 30:98-101.

Taylor, S.W., B.C. Hawkes, R.H. Silversides and M.G. Weber. 1991. Initial Effects of Prescribed Fire and Mechanical Site Preparation on Seedling Environment and Establishment on a Backlog NSR Site in Central Interior British Columbia. FRDA Report #177. B.C. Ministry of Forests. Canadian Forest Service. 29 P.

Thomas, D.F. 1983. The Use of Sheep to Control Competing Vegetation in Conifer Plantations. Proc. 5th Ann. Forest Vegetation Management Conference. Sacramento, Ca. pp. 138-142.

Timmer, V.R. 1997. Exponential Nutrient Loading: A New Fertilization Technique to Improve Seedling Performance on Competitive Sites. New Forests. 13: 279-299.

Wagner, R.G., and M.W. Rogozynski. 1994. Controlling Sprout Clumps of Bigleaf Maple with Herbicides and Manual Cutting. Western. Jor. App. For. 9(4): 118-124.

Wall, R.E. 1996. Pathogenicity of the Bioherbicide Fungus Chondrostereum purpureum to Some Trees and Shrubs of Southern Vancouver Island. Report. B.C. Ministry of Forests. Canadian Forest Service. 18 P.

Wall, R.E. and S.F. Shamoun. 1990. Experiments on Vegetation Control with Native Pathogenic Fungi in the Southern Interior of British Columbia. FRDA Report #134. B.C. Ministry of Forests. Canadian Forest Service. 17 P.

Weatherspoon, P. C. 1987. Prescribed Burning for Vegetation Management: Effects on *Ceonothus velutinus* Seeds in the Deff and Soil. Proc. 9th Ann. Forest Vegetation Management Conference. Redding, Ca. pp. 125-141.

Webster, J. and E.A. Fredrickson. 2005. Lessons Learned on 50,000 Acres of Plantation in Northern California. USDA Forest Service. Pacific Southwest Forest and Range Experiment Station. Gen. Tech. Rep. PSW-GTR-198

White, D. E. and M. Newton. 1989. Competitive Interactions of Whiteleaf Manzanita, Herbs, Douglas-Fir and Ponderosa Pine in Southwest Oregon. Can. J. For. Res. 19: 232-238.

White, D. E., L. Witherspoon-Joos and M. Newton. 1990. Herbaceous Weed Control in Conifer Plantations with Hexazinone and Nitrogen Fertilizations. New Forests. 4:97-105.

Whitehead, R. and G.J. Harper. 1998. A Comparison of Four Treatments for Weeding Engelmann Spruce Plantations in the Interior Cedar Hemlock Zone of British Columbia: Ten Years After

Treatment. Information Report BC-X-379. Canadian Forest Service, Victoria British Columbia. 21 P.

Young, B.W., C.A. Hart and F.R. Hall. 1987. The Use of "Dial-a-Drop" Concept in the Study of Droplet Impaction with Leaf Surfaces. Aspects of App. Biol. 14:23-33

Chapter 9: Planting

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Introduction

Prior to implementing the planting steps of a reforestation project, it is very important to consider how it fits with the other key steps to a successful reforestation plan. These key steps are based upon the following "Five Principles of Successful Reforestation" that have been developed and refined by reforestation foresters over the past several decades in California's Mediterranean climate:

1. Plant species from known, appropriate seed sources

Typically, this means tree species which are native to the site using seedlings that are grown from native, adapted seed as described in *Chapter 4 – Seed.*

2. Use quality seedlings

As described in *Chapter 5 – Seedlings*, seedlings must be grown using excellent, up- to- date nursery practices. Seedlings must be vigorous enough to grow roots down to permanent soil moisture during the first growing season of establishment and be able to withstand sun, wind, cold, and any other environmental conditions that might be encountered.

3. Control competing vegetation

During the critical first year of establishment in a typical Mediterranean climate, planted seedlings need all the available water in the soil that is within reach of the rapidly expanding seedling root system. The main cause of soil moisture depletion at the rooting level during the long, hot and dry summer period is transpiration from competing vegetation, and not evaporation. Experience over the past few decades has shown good control of competing vegetation results in soils retaining sufficient moisture to provide for very high survival rates, even on very dry sites during prolonged droughts. Mechanical and hand control methods as described in *Chapter 6 – Site Preparation*, can also be used to control competing vegetation but are most effectively done in combination with herbicides in order to minimize erosion and/or topsoil disturbance, and to effectively constrain costs. A very cost-effective method of vegetation control is through the carefully planned and regulated application of registered herbicides as described in *Chapter 8 – Vegetation Management.*

4. Properly handle, transport, store, and plant seedlings

This *Chapter 9 – Planting* describes the details of these critical reforestation steps. The information here has been developed and refined through many discussions with regeneration foresters with decades of experience across California. Unlike some of the other topics addressed in this book, these best management practices have rarely been done under research conditions where the results have been published. Generally, the most common and cost-effective method used in successful reforestation projects in California, especially interior California, is to use hoedads to plant relatively small, container grown stock. However other stock types and methods are appropriate in certain climates, soil types and other situations. For example, on coastal sites where competition for light is more critical and transpiration stress is less significant than on interior sites, larger seedlings are used and often planted with shovels rather than hoedads. Proper handling includes minimizing exposure to drying and high temperatures prior to and during planting. Proper planting includes planting deep enough so that the growing media is completely covered by moist mineral soil and ensuring that seedling roots are not bent over in the hole nor have air pockets around them. Proper timing means having soil moisture and soil temperatures adequate for root growth on the site at the time of planting.

5. Protect seedlings from damage by animal and insect pests if necessary

As described in *Chapter 11 – Damage*, there are many control methods to consider depending upon the specific animal and/or insect pest and reforestation site characteristics. It is important to consider that maximizing early tree growth by adherence to the previous four "principles" can greatly reduce the number of years that seedlings would need protection from possible browse damage by livestock and/or other animals.

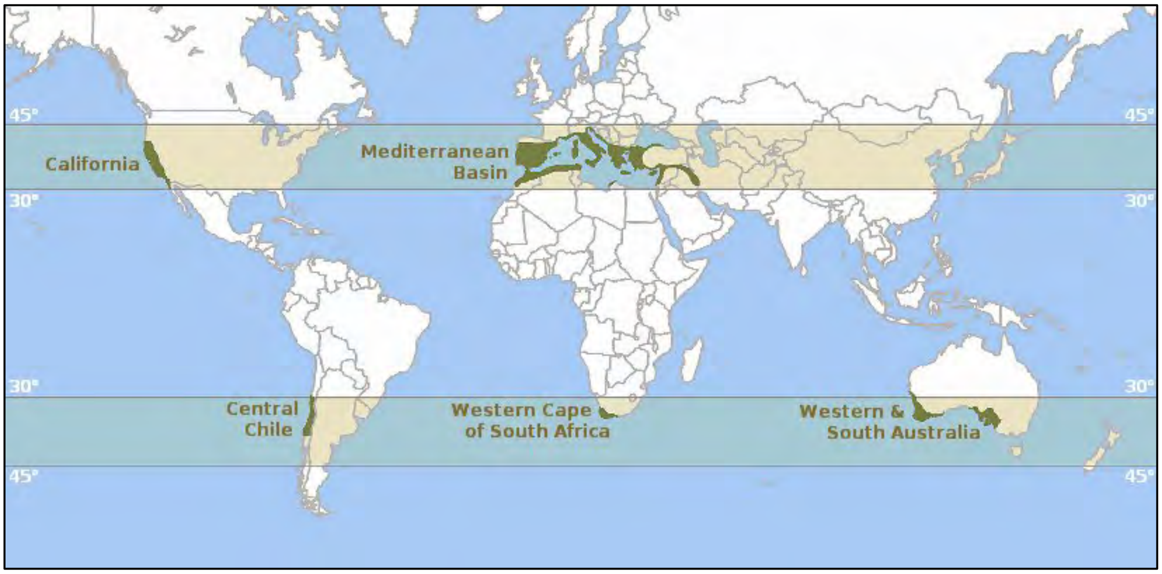

Figure 9.1 A "Mediterranean climate" is characterized by warm/hot, dry summers and mild/cool, wet winters. Therefore, soil moisture is the limiting factor for conifer seedling establishment.

Planting Season

The most appropriate times of the year to plant vary for different ecoregions in California. Even within regions, the optimal planting window varies by elevation, aspect, climatic conditions, soil and ground conditions, as well as planting site access. Depending upon these site-specific factors and the general region, planting typically occurs in California from fall through late spring. Since 2010 there have been a few successful operational-size planting trials conducted in late summer. These successful summer plantings have been completed on sites with good soil moisture due to recent thunderstorms and excellent control of competing vegetation throughout the spring and summer. Additionally, smaller container seedlings are grown in the nursery for a shorter period of time and lifted and packed in proper physical and physiological condition for summer planting. Late summer plantings should be done with caution until continuing success can be demonstrated in your region. The factors in the following sub-section should be considered in selecting the proper scheduling of planting times, especially if the forester has multiple planting projects to complete.

Central and Northern Coastal Area

Ideal planting times are determined by the species being planted, the distance from the coast, climatic conditions, elevation and aspect. Areas not planted in the late fall or winter are typically planted as early as possible in the spring. Since south and west slopes typically dry out before the east and north slopes, these slopes should be planted first.

Planting true fir at higher elevations of the North Coast region typically starts in November and progresses until access to, and planting of the units, is impeded by snow, typically in late December. Planting can then resume in the spring after snowmelt, sometimes occurring as late as May if snowpack persists into the spring. In general, redwood planting within its typical coastal range can start in November and continue into April, sometimes the first part of May, with the majority of redwood being planted January through March. Where redwood is planted at more inland and higher elevation sites at the fringe near the edge or outside of its typical range, commencement of planting typically is delayed until later in the season to avoid desiccation of newly planted seedlings from exposure during the coldest month(s) of mid-winter. Once redwood seedlings at these locations are established at the end of the first growing season with deep roots, winter desiccation is not usually a problem.

West and East Sides of the Sierra-Nevada/Cascade Ranges

The variable elevation, aspect, soil, and climatic conditions dictate the planting schedule for specific locations within this broad region. Latitude can also affect planting timing, with southerly latitudes opening sooner for planting than northerly latitudes at the same elevation. Planting in this region occurs primarily in the spring planting season that occurs from late winter through the advent of drier late spring conditions. However, fall planting has become increasingly common and successful at higher elevations (if seedlings are insulated during harsh winter weather by snow), primarily on the westside, but also in limited situations on the eastside. Typically, spring planting on the westside Sierra/Cascades extends from February to late March or early April at lower elevations (1,500 feet to 3,500 feet), March through April at mid elevations (3,200 feet to 5,000 feet), and mid-April to late June at the higher elevations with late snowpack melt. On the eastside, planting season is typically from April to late May, and any high elevation sites (above 5,000 feet) may not be accessible until a May to late June period. These timeframes will be dependent on local conditions such as aspect and site conditions and can vary from year to year depending on weather patterns. Table 9.1 shows the approximate planting dates by area and elevation.

Table 9.1 Approximate Planting Dates in California Sierra/Cascade Regions

Area	Elevation	Planting dates
Westside “low” elevation	1,500 feet to 3,500 feet	Feb through early April
Westside “mid” elevation	3,500 feet to 4,500 feet	March through April
Westside “high” elevation	>4,500 feet	April through June or Sept. through Oct.
Eastside “low” elevation	3,200 feet to 5,000 feet	April through May
Eastside “high” elevation	>5,000 feet	May through June or Sept. through Oct.

Source: Personal communication with numerous experienced reforestation foresters

For any of the indicated spring planting periods, planting in the Sierra/Cascade and eastside regions should begin as soon after snowmelt as possible and when soil temperatures are at least 38 to 40 degrees Fahrenheit and rising. For large spring planting projects that require several weeks of planting to complete, lower elevations should be planted first and within any particular elevation, south facing aspects should be prioritized, followed by west, then east, and lastly north facing aspects. Also, within these elevational and aspect considerations, soils with relatively lower water holding capacities should be prioritized.

Considerations for Fall versus Spring Planting in the Sierra Nevada/Cascades and Eastside

The principle behind fall and spring planting lies in the fact that most conifer species have two primary root growth periods in a year. The spring growth period is stimulated by climatic conditions favorable for root and shoot growth, including increasing day length, warming atmospheric and soil temperatures, and an abundance of moisture from seasonal rains. This period of conifer growth is characterized by the highest a rapid extension of both the roots and the shoots metabolic activity of the year as seedlings rapidly extend both roots and shoots, with root growth initiating before shoot growth. The other time of year that conifers have the capability of growing roots is in the late summer and early fall when temperatures start to moderate, and the days are becoming shorter. The fall season is also a period of reduction in transpiration of deciduous trees and herbaceous vegetation, which allows soil moisture levels to rise. Planting in the fall has historically yielded unpredictable results, at least in part due to unpredictable winter weather conditions. Wind or exposure to sunlight without adequate snow cover can result in seedling desiccation, particularly since no root uptake occurs in cold soils. All these factors typically made spring planting the safest and most commonly used planting timing in reforestation. However, in recent years, reforestation foresters have developed more expertise on when, where, what and how to plant in the fall. Several factors should be considered when making a decision to plant in the fall and certain strategies will maximize success and minimize risk if it is decided to plant in the fall.

Planning a fall planting project requires focus on the basic reasons for choosing to not plant in the safer spring planting window. Four such justifications include:

1. Planting on high elevation sites that would be covered in winter snowpack until very late spring and/or the onset of summer drought.

2. Planting on sites where access may be blocked by high passes that are normally covered in snowpack until late spring or by snow that persists on significant distances of roads shaded by forest cover. Snowpack on a planting unit(s) exposed to direct sunlight typically melts off weeks before shaded or high elevation access roads are open for travel to the planting site.

3. Decrease extended seedling storage time that is required when planting in late spring. Seedlings must be lifted and packed and put into refrigerated or freezer storage at the optimum lifting time (December or January) which is months before the optimum planting time at higher elevations (May or June).

4. Divide operational challenges of large planting projects between two planting seasons.

Conditions needed for fall planting are the same as any other planting timing, i.e. adequate soil moisture, warm soil temperatures, mild diurnal air temperatures and adequate humidity. Timing is even more critical in the fall. Ideally, seedlings should be in the active root growing phase typical of the late summer and early fall. The fall planting window is generally late August through October for most sites. Ideally, high elevation sites should be planted when enough growing season is left for adequate root growth to occur. Planting in mid to late October may result in very little or no root growth at high elevations. However even if the seedlings are planted this late planting can be successful if the seedlings are covered with snow during the winter. In this case, the seedlings are essentially being stored under a blanket of snow until spring thaw. If these seedlings are protected from desicating winds and low humidities by winter snow, then they will get an earlier start on establishment and growth in the spring than will similar seedlings planted later in the spring.

Figure 9.2 (left) Significant new fall root growth on white fir within two weeks after planting on October 5, 2010 compared to the white fir in **Figure 9.3** (right) planted a week later (October 12, 2010) with almost no new root growth two weeks after planting, both at 5,500 foot elevation in Plumas County on private land burned in the Moonlight Fire. Although fall planted seedlings that were planted after mid-October did not initiate new growth until the spring after planting, they did survive the winter and initiated vigorous new root growth in the spring much sooner than the seedlings which were planted spring 2011 initiated root growth.

In general, the best time for fall planting is as early as the soil moisture is present provided that soil temperatures are still high enough for root growth or an insulating winter snowpack is imminent. The uncertainty in California's climate for suitable late summer or early fall rains during any given planting year can be significantly mitigated with effective weed control. Although late summer or early fall rains can provide the necessary soil moisture, complete control of competing vegetation during the entire growing season prior to planting is an effective strategy to retain the necessary soil moisture to begin planting. Most forest soils, especially at higher elevations, can maintain adequate soil moisture within the lower rooting zone of seedlings even by the end of summer if transpiration from competing vegetation has been completely controlled on the planting site. If vegetation control has not been completed throughout the entire growing season, then sufficient late summer or early fall rains are necessary to ensure adequate soil moisture for early fall planting.

Areas prone to drier conditions should be avoided for fall planting because of risk of desiccation. Eastside sites, especially at relatively low elevations (less than 5,000 feet) can be very risky due to the high probability of very low humidity (less than 20%), high winds, or soil temperatures that become too cold for water uptake by existing seedling roots. These conditions can desiccate the seedlings before they have the time to grow new roots. When planting at higher elevations, consideration of aspect is important because south facing aspects and/or windswept areas may become void of adequate snow cover in the winter period, exposing the newly planted seedlings to extreme low temperatures and drying winds. North facing slopes that are likely to be snow covered all winter are generally safer for fall planting. Small regeneration units with surrounding mature trees that provide winter shade on most of the unit will retain more snow than large units that are open to direct winter sunlight.

Other areas where fall planting should be avoided are areas that have high populations of deer or elk during the late fall or winter that historically browse on conifer seedlings. Areas that are traditional wintering grounds for these herbivores should not be fall planted, since the only succulent green vegetation during this time of year may be the newly planted conifer seedlings.

When planning a fall plant, it is important to communicate to the nursery manager when placing the sowing order, that you plan to lift the seedlings for a fall planting program if site conditions are suitable. The nursery manager should make sure that the seedlings are sown early enough to achieve a suitable maturity to lift between late August and very early October (depending upon species and elevation of planting site) if the project conditions are favorable. The nursery will also have to plan ahead to accommodate fall packing, and this needs to be discussed with them early in the growing season. At the time of lifting in the nursery it is important to remember that the trees need to be actively growing roots and be kept in that condition until planting time. This type of planting is considered “hot planting” and seedlings are not to be put in cold storage. Storage temperatures should not be less than 40 degrees Fahrenheit or the trees may be pushed into dormancy and not grow roots. As planting time nears, the nursery should be instructed to only lift and pack the number of seedlings that can be planted in one week or less. The nursery should not put liners around the boxed seedlings, as carbon dioxide (CO_2) may build up very rapidly due to the high rate of respiration of the trees. All seedlings that are lifted and packed for fall planting must be planted at that time, because they are not capable of surviving long term storage when lifted and packed at that time of the year. This is because seedlings do not reach a high level of cold hardiness and low metabolic rate, which are necessary for long term storage, until mid November, which is the start of the normal lifting window for long term storage. Container stock is preferred over bare-root stock for fall planting due to the ability to lift and ship one week’s production or less on short notice and also because it is very difficult to lift bare-root seedlings while the roots are actively growing without damaging the roots (e.g. stripping the cambium layer away from the root).

Summary of Advantages of Fall Planting

- Seedlings planted in the fall will initiate root growth before winter if planted in September or early October. However, even if seedlings are planted later in the fall they will initiate spring root growth sooner than seedlings planted in the spring.

- Fall root growth can occur immediately after planting if the seedling and site conditions allow planting in September or early October.

- Costs of plowing snow and/or long seedling storage are eliminated, as are the risks of late spring-early summer planting. Also more time to conduct the entire annual planting program is available if needed.

Summary of Challenges and Risks with Fall Planting (especially east of the Sierras/Cascades)

- Coordination and scheduling with nursery and planting contractor for seedling packing, transportation and planting is more complex due to “hot planting”, with no more than one week’s production for each pack out.

- Sometimes on the eastside, the normal summer dry season extends into the fall with the first significant precipitation coming in the form of snow, especially above 5,000 to 6,000 foot elevations.

- Low relative humidities on the eastside in the fall can exacerbate transplant shock and/or subsequent stress on seedlings.

- Wind or extreme temperatures with no protective snow pack after fall planting can damage or kill newly planted seedlings.

- On sites where mechanical sub-soiling or ripping has been conducted, planting should not occur until significant precipitation has settled the disturbed, loose soil. Reforestation projects have experienced higher than acceptable mortality rates when fall planting has been preceded by such mechanical treatments in the summer of the same year. So, it is now standard practice to either avoid sub-soiling/ripping on sites scheduled for fall planting, or to schedule fall planting at least one full winter after sub-soiling/ripping in order to allow the disturbed soil to properly settle prior to planting. Or if it is necessary to sub-soil/rip and it is necessary to schedule it for the same year as fall planting, then seedlings are planted in the undisturbed, firm soil inbetween the sub-soiled/ripped rows.

- Unanticipated delays in the timely completion of scheduled logging or site preparation activities presents a risk that a scheduled fall planting program might be reduced in scope or cancelled. This can be mitigated by scheduling fall planting a year or more after logging. Although this might delay planting a year, it provides more certainty for scheduling the prescribed reforestation steps. Completing logging or mechanical site preparation in the year prior to fall planting allows for the scheduling of a spring herbicide treatment which can result in the retention of adquate soil moisture throughout the summer and early fall regardless of the amount of late summer or early fall rains.

Species, Stock Types, and Spacing across California

Seedling species and stock types are discussed in detail in *Chapter 5 – Seedlings*. These sections provide some practical lessons from decades of experience with reforestation plantings in these regions of Northern and Southern California.

Sierra/Cascades and Eastside

Species

Species selection by landowners/managers is more variable in these interior sites than in the coastal redwood dominated areas. Generally, landowners and managers want to plant a mix of species that are adapted to surviving and growing well on the site. Diversity of adapted species increases forest stand health since most pests are "host species specific" and it also diversifies future marketing options for the trees that will take several decades to grow. On many sites throughout this region the percent of shade tolerant species far exceeds the pre-settlement, more fire-adapted mix with a higher proportion of shade intolerant species, especially at low to mid elevations on the westside and most of the eastside. Decades of partial harvesting, the ingrowth of more shade tolerant species, and fewer wildfires that result in relatively more mortality to thin barked species such as white fir often result in a distribution of current species that are not necessarily well suited to future climatic conditions. Although seed disseminated from adjacent shade tolerant species, such as WF and IC, typically become established in group selection and clearcut size regeneration units, natural regeneration may not occur in the event of a large, stand replacing wildfires. DF is much more susceptible to late spring frost damage than other conifer species, so other suitable species should be planted in frost pockets that might occur within a planting unit.

Where natural regeneration of shade tolerant species, such as white fir (WF) and incense cedar (IC) can be expected to seed in over time, less shade tolerant species such as PP, SP and DF are the focus of planting. This is especially true for landowners and managers that primarily practice single tree selection silviculture which favors the natural establishment of IC and WF over PP, SP, and DF.

Based on informed expectations of future site-specific climatic conditions, species should be selected that are accordingly adaptable to be resistant/resilient to drought, fire, pests and pathogens. In some areas, this can mean a shift towards a species mix of more drought tolerant pine species even if the site is currently dominated with white fir and incense cedar trees.

Soil type characteristics such as Available Water Holding Capacity (AWC), depth to bedrock, and texture can also influence the best mix of planted species. Although a site might be within the general location and elevational range where one might normally plant a 50:50 ratio of PP and DF, a soil type with relatively low AWC is a reason to increase the percentage of more drought resistant PP, especially on south aspects or sites with relatively low average annual precipitation.

Size of regeneration unit in proximity to adjacent seed sources. At lower elevations (i.e., below 3,000 feet and eastside up to 4,500 feet) a typical seedling mix of 50 to 100% PP (and/or JP where appropriate on the eastside and ultramafic westside soils) with some DF and IC seedlings on suitable sites may be appropriate, depending upon objectives. A typical seedling mix from 3,000 feet to 4,000 feet on the westside is 50% PP and 50% DF, with some IC if appropriate. A mid-elevation (4,000 to 5,000 feet) westside species mix commonly planted is 35 to 50% PP, 5 to 20% SP, 5 to 20% IC, 20 to 35% DF, and 10 to 20% WF. At elevations above 5,000 feet, increasingly more WF or RF are planted with RF replacing WF as elevations increase above 5,500 feet and JP replacing PP. Ponderosa pine and/or JP are often not included in the species mix at all above 6,000 feet depending upon the specific location. Some landowners have not only planted giant sequoia (GS) within its current narrow range but have also planted up to 5% GS on suitable sites in the Northern Sierras well outside its current range but where GS grows really well and where it may be better adapted to future climates. Such sites selected for planting GS typically are characterized by relatively high site class and high water holding capacity soils.

Stock Type

The selection of stock types in this region are based on several factors, including the following considerations to ensure seedlings can survive the critical first year of establishment during the long dry and hot summers typical of these regions:

- Minimize foliage height to reduce transpiration stress.

- Maximize first-year root growth (to below depth of late summer soil moisture).
- Small enough to plant with hoedads.
- Sturdy stem, buds, and healthy foliage.

To reduce transpiration stress and promote rapid, deep root growth during the critical first growing season, almost all seedlings planted in interior California are relatively small one-year-old container grown stock that have vigorous, juvenile roots. Stryo 5's are the most common ponderosa pine (PP) stock planted with some foresters in recent years planting even smaller, Styro 4 PP. Styro 6 PP are also planted to a far lesser degree than in the past, and even much less frequently Styro 8 PP are planted. Styro 6 is most commonly planted sugar pine (SP) seedling. Styro 6 and Styro 8 are the most commonly planted DF, true fir and IC stock sizes because these species, especially DF, are more susceptible to sun scald on the basal stem compared to PP. Although more expensive, the slightly larger stem diameter and more pronounced lateral branching of Styro 8 DF provides more shade on the stem, which is especially important at lower elevations. If a larger DF seedling with even more lateral branching is needed then more expensive Styro 10-77's, which are grown in styrofoam containers that have only 77 cavities, are planted. On eastside ponderosa pine sites in northeastern California, some landowners still plant two-year old bare root PP seedlings using shovels or hoedads with relatively long, wide blades.

Spacing

Seedling spacing in the Sierra/Cascade/Eastside regions depends on many factors including the landowners' objectives and commitment to follow-up with pre-commercial thinning (PCT), site quality and conditions, risk, seed availability, level of competing vegetation, funding availability and window, and anticipated first-year seedling survival rates by species. When harvesting healthy trees on private land, compliance with the minimum stocking standards of the California Forest Practice Rules (FPR) must be considered. As of 2020, the stocking standards in the California Forest Practice Rules (FPR) vary by site quality and are in line with stocking standards on private lands in other western states.

Table 9.2 2020 Resource Conservation Stocking Standards for Minimum Stocking (trees per acre)

CA FPR Site Quality	Coast	Norther / Southern
I	200	125
II	200	125
III	125	125
IV	100	100
V	100	100

Source: California Department of Forestry and Fire Protection. 2020. California Forest Practice Rules 2020. Pages 306: State of California.

Currently, there are no reliable pulp markets in the Sierra/Cascade/Eastside regions of California and wood fuel chips and small logs are low (or negative) value by-products of final harvests or intermediate forest thinning projects. As a result, sawlog or peeler size trees that are 12 to 18 inches diameter at breast height are the primary objectives of most private forest landowners when determining seedling spacing at planting or at PCT. Although ideal density will vary by species and site, it should generally be at 100 to 180 trees per acre by age 10 to 15 years to reach desired tree sizes for the first commercial thinning at age 35 to 50. This was historically accomplished by planting at higher densities of approximately 258 to 436 trees per acre, depending on species mix, followed by a PCT in 7 to 10 years. However due to improved seedling survival rates, some landowners planted seedlings at wider spacing, often from 135 to 222 trees per acre after wildfires and other catastrophic stand replacing events that did not require restocking under the FPR. The 2020 California Forest Practice Rules stocking standards have been revised to reflect the experiences of successful reforestation after wildfires that did not require extensive precommercial thinning and the management of the additional fuel load they created.

It was common in California to plant fewer trees per acre after wildfires when the forest practice rule of 300 trees per acre did not apply. Planting fewer initial trees per acre can reduce immediate costs as well as some or all of PCT costs to achieve the desired density of commercial trees. However, in low elevation Sierra/Cascade ponderosa pine, as well as eastside pine sites where excellent survival is anticipated, planting 135 TPA (18 feet by 18 feet) to 170 TPA (16 feet by 16 feet) is becoming more common. This is due to exceptionally high survival rates of PP and JP, the desire to minimize seed use, and to reduce seedling, planting and future PCT costs and fire hazard from PCT slash.

North Coast Region

Species

The larger redwood companies typically plant 75% redwood and 25% Douglas-fir (DF) mixes on upland sites and pure redwood on flat alluvial sites. Factors reforestation foresters consider when determining the species mix for a particular reforestation project must always consider the availability of suitable seed by species, climate, soil types, site elevation and aspect, appropriate species, and unplanned natural ingrowth. Sites where the soil types have lower Available Water Holding Capacity (AWC) or south facing aspect have more moisture stress on seedlings and may do better with more Douglas-fir and less redwood. Conversely, sites that consistently have more fog can support more redwood.

Stock Type

For many years, redwood seedling production consisted of two-year old bare-root or plug-1 stock. These stock types have a woody stem that is far more resistant to damage from animal browse than seedlings with green succulent stems. However, it is now difficult to find a bareroot nursery in a location where the minimum winter temperatures are mild enough for redwood production. Improvements in container nursery technology have allowed foresters to shift much of the production to two-year old containerized Styro 15s. These large container trees do not sustain as much damage to the fine root systems when lifting as bare root seedlings. Since the coastal climate results in relatively less soil moisture loss and transpiration stress than interior climates (where much smaller stock types are preferred) the larger foliage does not create as much transpiration stress on seedlings during the first growing season in coastal redwood climates. However, it is common practice to mow the tops of containerized redwood seedlings to keep the crown from getting too large in order to reduce transpiration stress after planting.

It is fairly common to see redwood seedlings turn reddish brown the first few years after planting, particularly on colder sites. Sometimes the tops will even die off. However, even if the top appears completely dead, the trees will often resprout from the root collar the next season. In these situations, foresters typically dig up a few such seedlings to inspect and determine if the seedling is still alive below ground. Inspection is done by scraping the cambium at the base of the stem and looking for moisture and/or creamy color to see if the seedling is alive. It is important to take the time and monitor whether or not foliage dieback is fatal to the seedlings or if they are still viable before investing in a replant.

Common stock types for DF in the Coast Region are one-year old Styro 8 and Styro 10 container seedlings. These are commonly grown at a greenhouse nursery in interior Northern California where colder temperatures, and careful control of temperature and light within the greenhouse, condition these seedlings to withstand planting site conditions. Douglas-fir stock types as small as Styro 6 have also been successfully planted by some landowners. Container nurseries can provide much more flexibility in the timing of lifting and packing seedlings than bare root nurseries, which is important when scheduling a planting project around specific planting site conditions. Also, DF can be forced into dormancy by the use of dark-out technology in the greenhouse. This method of inducing dormancy does not stress the seedlings, unlike the method of withholding water and nutrients. Two-year-old bareroot and plug-1 transplant DF seedlings are still used on the coast, especially on sites where sunscald or animal damage is a problem. Although plug-1 stock is more expensive than 2-0 bareroot, there is less damage to the fine roots when lifting and packing.

Spacing

Since planted seedlings often times get outnumbered by the redwood sprouts, it is more cost effective on units that are sufficiently stocked with sprouts to not plant redwood or plant as few as 50 redwood seedlings per acre. Approximately 5% of regeneration units can meet redwood stocking objectives solely with coppice regeneration. However, in redwood units with few sprouts, typically as many as 200 redwoods are planted per acre with up to 150 redwood clones and 50 redwood seedlings totaling 200 planted trees per acre (TPA). Although the range of planting density varies with the level of resprouts, on average within redwood units, approximately 120 seedlings per acre are planted. Redwood planting has been expanded into some areas of DF/tanoak timber type at higher elevations than redwood occurs naturally, but still generally within the redwood region. Outside of the redwood range, DF is commonly planted in the coast region at 300 to 435 TPA depending upon ownership and site.

Southern California Mountains

Due to the lower latitudes of Southern California, the dry season is longer, and temperatures are generally higher than in Northern California forests. These considerations along with Southern California's generally lower average annual precipitation, means the timing of planting projects in this region is even more critical and usually involves shorter planting windows. If the "Five Principles of Successful Reforestation" described in the introduction to this Chapter are followed, especially the elimination of competing vegetation to extend the window of suitable soil moisture during seedling establishment, a suitable planting window should be available to complete a successful planting project.

Planting in this region occurs primarily from December through February but at higher elevations can extend later into spring. Ideal planting times are determined by distance from the coast, climatic conditions, elevation and aspect. Since south and west slopes typically dry out before the east and north slopes, these slopes should be planted first. In addition to the factors listed for other regions, the periodic occurrence of extremely dry, warm spells and especially east winds known as "Santa Ana's" must be considered in scheduling planting operations and avoided.

Receiving Seedlings from Nursery and/or Cold Storage

The importance of monitoring the growing, packing, and storage practices at the nursery is mentioned in *Chapter 5 – Seedlings* along with a description of what a forester should look for in visits to the nursery. Then seedlings should be inspected upon receipt from the nursery and placed into a cold storage facility and monitored periodically until the day of planting. Upon receipt from the nursery a forester should inspect the following seedling conditions:

- Identification. Boxes or bags are properly labeled with name of forest owner/manager, seedlot number, species, stock type, seed zone, and elevation. The quantities of each seedlot should be verified against the nursery's packing list. In addition to a label on the outside of each seedling box, it is important to have the nursery place a label on the inside of the box in case the label on the outside of the box detaches during later transport or handling.

- Morphological standards. Seedlings should meet the morphological specifications in the nursery growing contract (i.e. stem height and caliper and root length). Note that there are rare occasions when accepting seedlings that do not meet specifications, particularly stem height, is preferred to delaying planting for a year or more, which usually also creates the need for an additional site preparation treatment.

- Acceptable root pruning. Roots of bare-root seedlings should be consistently pruned to specified lengths and the root cambium should remain intact (not stripped away or otherwise damaged during lifting and/or packing).

- Moist but not waterlogged condition. If seedling roots and/or shoots appear to have dried out, the plant moisture stress should be measured. Seedlings and roots should be moist but not immersed in standing water within bags or boxes.

- Signs of physical damage. This includes examining foliage, terminal buds, stem cambium and roots. Careful inspection of bareroot seedlings should be made to make sure stem and/or root cambium of seedlings were not stripped during lifting, pruning and/or packing.

- Signs of destructive molds/fungi. It is critical that seedlings are inspected for destructive molds/fungi upon receipt from the nursery and also periodically during cold storage. Botrytis and other such destructive fungi can severely weaken or kill seedlings regardless of how well seedlings are subsequently planted and cared for. Destructive molds or fungi may appear dark and/or "slimy" and/or cause the bark and cambium to easily dislodge from the stem. However, some fungi that typically show as a whitish fuzz connected to the foliage of seedlings that have been in long term cold storage are not harmful. Mycorrhizal fungi that appear on roots are even beneficial. When in doubt, it is important to immediately consult with an experienced reforestation forester and/or nursery manager to properly determine if fungi appearing on seedlings are destructive or harmless. Planting seedlings with destructive molds or fungi such as Botrytis is putting "good money after bad" and not worth the cost and effort even if the seedlings otherwise appear alive and green. After receipt from the nursery and inspection, seedlings must be placed in cold storage facilities immediately and monitored periodically until the day of planting, unless the seedlings were lifted and packed to be kept out of dormancy for fall planting. Seedlings lifted and packed for fall planting should be kept in shaded storage above 40 degrees

Fahrenheit to prevent root dormancy. Such seedlings must be planted within one week after lifting to maintain good health and vigor and to prevent Botrytis infestation. Key elements of cold storage for seedlings that should be kept dormant until winter or spring planting are:

- Storage facility temperature should be 33 to 35 degrees Fahrenheit. If the facility does not have a functioning commercial hydro-thermograph, then a strategically placed "Hi-Low" thermometer(s) or a continuous digital recording device is helpful in daily monitoring of the cold storage unit. A long probe thermometer(s) is useful to monitor temperatures inside the seedling boxes or bags. Modern digital data recorders are small enough to be placed inside seedling box and are capable of recording temperature data remotely for many days.
- Seedling boxes or bags should not be open in order to avoid drying out the seedlings.
- There should be proper air circulation in the storage facility with seedling boxes at least 4 inches away from walls, stacked on pallets (if feasible), and at least one side exposed to circulating air.
- If diesel-powered refrigerated vans are being used for temporary cold storage, then the oil and fuel levels of the motor supplying power to the refrigeration unit should be monitored, along with the refrigeration coils and fan. The temperature in both diesel and electrical powered refrigerated vans should be checked daily as refrigeration unit break downs occur periodically and should be repaired within 24 hours. Foresters using refrigerated storage, especially vans, routinely arrange for mechanic(s) skilled in refrigeration to be ready and available for repair work on short notice. Caution should be used in placing seedling boxes immediately in front of the refrigeration unit where colder temperatures from the air blown by fans can sometimes leads to frozen seedlings.
- Refrigerator coils should be checked daily for excessive frost as it could impair proper functioning, especially in refrigerated vans. The higher the relative humidity in a cooler, the more likely excessive frost can occur. It has been observed that icing of the refrigerator coils occurs more frequently after wet seedling boxes have been loaded into cold storage on rainy days. Although electric defrost coils installed in storage units can reduce icing problems, the coils still need to be monitored as icing can still occur. With the use of container seedlings and/or current packaging techniques for all seedling stock types, excessive drying of seedlings in cold storage rarely occurs. However, it is important to make sure seedlings, especially bareroot seedlings, are not directly exposed to drying air. Once seedling roots dry out, they are dead. If packaging and seedling stock type do not keep seedlings sufficiently moist, bucket(s) or barrel(s) of water can be

placed in the cooler with burlap sacks placed over the sides to soak up and wick the water, to increase humidity.

- Although long-term storage is not ideal, when the planting site is not ready until late spring, seedlings that were cooler stored and never frozen can last for 3 to 4 months if lifted and packed at the proper time and stored properly. Alternatively, as discussed in *Chapter 5 – Seedlings*, seedlings can be put in freezer storage if a longer storage period is anticipated. However, once freezer stored seedlings are thawed they do not cooler store as well as seedlings which were never frozen. So, after thawing and placed in cold storage, seedlings should be put planted as soon as possible, preferably within a week.

Transport, Handling, and Storage in the Field

Importance of Seedling Care

As described in *Chapter 5 – Seedlings*, the proper handling and cold storage (refrigerated or freezer) of seedlings at the nursery and transport to, and storage at, a temporary refrigerated or freezer storage facility (if not available at the nursery) is critical. Conifer seedlings must be in the best physiological shape to survive and thrive in the harsh field conditions that may be encountered during establishment in the first growing season.

Physically damaged seedlings expend resources to repair the damage. Seedlings exposed to temperatures above 35 degrees Fahrenheit are subject to undue respiration which depletes carbohydrate reserves that are otherwise used for survival and growth after being planted into a harsh environment. Foresters need to plan, communicate, and coordinate well with nursery and storage facility manager(s) and planting crews to ensure that seedlings are packed, stored, transported, and planted at the best time and under optimum conditions. Although it is critical to maintain container grown stock free from physical damage and at proper storage temperatures, bare-root seedlings are even more susceptible to climatic stresses during field transport, handling, and planting. Without soil media surrounding the roots, bare-root stock is especially susceptible to root damage or death by desiccation.

Seedling health and vigor must be carefully maintained from the time seedlings are transported from the nursery (and/or local refrigerated or freezer storage facility) to planting in the ground.

Transportation from Nursery and/or Storage to Planting Site

To minimize seedling stress and loss of vigor, only the number of seedlings to be planted that day should be picked up and transported to the planting site. Seedlings scheduled for planting later are best left in cold storage. Seedling boxes and bags should be handled with care (e.g. no dropping, excessive sliding or impacts) to avoid damage to seedlings. Seedlings are typically transported from cold storage to the planting site in the bed of a pick-up truck or trailer. In situations where there is no road access to the planting site, seedlings may need to be further transported using yarders, helicopters or all-terrain vehicles (ATV's). Since planting crews typically start planting at first light in the morning, the seedlings need to be picked up and transported to the planting site before sunrise.

However, if transportation occurs while the sun is shining or in low relative humidity (i.e. less than 30%), the seedling boxes or bags should be within an insulated tree box with reflective outer surface. Absent such a storage compartment, the boxes or bags should be covered with a "planting tarp". A typical "planting tarp" consists of a silver reflective layer on the inside (placed against the seedling boxes or bags) and a white reflective layer on the outside (facing away from boxes and bags). Never cover seedlings with a regular plastic or canvas tarp that is not constructed specifically for planting (i.e., a "planting tarp") as that could increase rather than decrease ambient temperatures around the seedling containers by absorbing rather than reflecting radiant heat. Seedling container temperatures should be checked upon pick-up from the cooler and monitored throughout the day until seedlings are placed in the planting bags. Particular care should be taken if the weather is sunny, hot, windy, and/or dry, especially when planting bare-root seedlings.

Handling Seedlings at the Landing or Daily Storage Site

Tree seedlings should be kept sealed in their container boxes or bags until placed in the planting bags. Seedling containers must be kept out of direct sunlight at the planting site and stored under secured "planting tarps". If shade is available, it is advisable to park the pick-up truck or trailer in the shade even if an insulated, seedling trailer or storage box is used. If a pickup with a reflective "planting tarp" is used and cannot be parked in the shade, then the seedling boxes or bags should be removed from the pickup and placed in the shade of tree(s) or the pickup and covered with the protective "planting tarp".

Planter Handling at the Landing or Other Daily Storage Site

Planters should use planting bags to carry seedlings that are specifically made for planting small conifer seedlings.

Container Seedlings

Container grown seedlings are often packed in small plastic bags containing 15 to 20 seedlings which are then packed together in a larger container, usually a box that is lined with a large plastic bag. Seedlings should be placed in the planting bags either with or without their plastic seedling bags such that the roots are protected from sunlight and dry air. Avoid packing seedlings in the planting bags so tightly that they are damaged and/or prone to accidental spillage when an individual seedling is pulled out for planting. Seedling roots must not be allowed to dry out. Planters should not "bag up" until they are ready to plant including after, not before, taking a break. Planters should only pack planting bags with enough seedlings that can be planted within one hour on days that are warm, dry, windy, or sunny.

Bare-Root Seedlings

Consider packing fewer trees per "bag up" when planting bare-root seedlings on hot and/or dry and windy days. Bare-root seedlings should be dipped in water prior to placing them in bags. On warm, dry days some foresters mix vermiculite or another additive such as Terra-Sorb® Planting Gel (manufactured by Lebanon Seaboard Corporation) in the water to retain moisture. However, the literature is not conclusive on the benefits of additives to the dipping water. It is important to drain excess water from the bottom of planting bag so that roots are not immersed in water long enough to be damaged by asphyxiation.

Seedling Handling During Planting

Each seedling should be pulled gently from the planting bag one at a time and only after the planting hole has been prepared using a planting tool for placement of the seedling. Holding multiple seedlings in one hand outside of the bag or holding a seedling while preparing the planting hole (i.e. holding it and planting tool in same hand) is a common cause of cambium damage and weakening of seedling vigor. In addition to risking stem or root cambium damage, holding seedlings outside of the planting bag any longer than the time necessary can expose the roots to desiccation and possible death. Planters should not prune individual seedling roots in the field. Although all bare-root seedling roots should be pruned to the proper length at the nursery just prior to packing, if some seedlings were not properly pruned, then any subsequent root pruning should be done under the supervision of the forester at the landing (site where boxed or bagged seedlings are stored for the day and distributed into planting bags). Heavy-duty paper cutters or sharp machetes have been used on the rare occasions that pruning at the landing was necessary. Seedling roots should then be dipped in water and immediately placed in the planting bags for planting as soon as possible.

Planting Methods

Essential Steps

Proper planting methods must be followed to ensure success. The following steps are essential to any reforestation project:

- Store trees prior to planting in an area selected by the landowner's representative and under conditions specified and monitored by landowner/manager's representative.

- Keep the root system of all planting stock, between storage and planting, moist at all times. Only remove one seedling at a time from planting bag immediately prior to planting (i.e. only after opening planting hole with the planting tool).

- Plant the area in an organized manner so that systematic inspection can be maintained.

- Scalp each planting spot down to bare, moist mineral soil to remove dry soil, slash, snow, and other dead and live vegetation. No duff or debris shall be allowed to enter the planting hole. Prior to starting the planting hole, the edge of the hoedad or shovel should be used to "scalp" an area of sufficient size (i.e. approximately one-foot diameter) down to moist mineral soil such that only moist mineral soil will fall into the planting hole when it is opened and then closed around the seedling roots. If not instructed otherwise, sometimes planting contractors (and some reforestation foresters) do not require crews to spend the extra time to scalp when the surface of the soil is wet or when it's raining. However, besides making sure no dry soil or snow can fall down into the planting hole, scalping is also used to clear away woody debris, grasses, forbs and/or surface rocks that could potentially fall into the planting hole around the seedling roots. Also, scalping live grasses and forbs prior to planting facilitates protection of tree seedlings during a follow-up release spray treatment. Grasses and forbs rooted at the base of planted seedlings are likely to be missed when seedling protectors are placed around the seedlings to protect them during release spray. Heavy, deep accumulations of slash can make it difficult to plant with hoedad, so this needs to be considered when planning and implementing site preparation activities.

- "Break out" each planting hole by opening it to the extent necessary to assure that only friable soil is packed around the roots of each seedling.

- Plant each tree in an erect/vertical position so that the tops and roots are perpendicular to the horizontal plane. Ensure that the roots are not twisted, tangled, matted or curled at the ends (i.e. no "J" or "L" roots) and only moist soil is placed against the roots. The total root system must be covered with moist soil.

- Plant each tree so that the root collar is at the natural undisturbed ground line of the planting spot. When container grown nursery stock is used, the top of each "plug" must be covered with soil to prevent exposure of the potting mix to the atmosphere. Allow the planting hole to backfill with moist soil and minimal rock, without woody debris or snow and leaving no air pockets.

- Compact the soil around the root system by lightly tapping the ground (do not use a hard stomp that would cause too much compaction) so that the tree does not pull loose by a tug strong enough to detach a group of needles.
- Maintain the desired spacing and TPA.
- Do not plant seedlings in a road drainage facility or within 8 feet of any road. Consider leaving the log landings and other selected areas unplanted to facilitate equipment and personnel access and safety for future management activities and fire suppression efforts.
- Field culled seedlings should be laid on the ground alongside a planted tree so planting inspectors know they were intentionally left unplanted because they were considered cull and were not otherwise intentionally or accidentally abandoned. If feasible, requiring the planter to tie the stem of the field culled seedling in a knot ensures that it was placed on the ground intentionally as a cull.
- Root pruning should be allowed only at the time when trees are being placed in the planting bags and should be done under the direction of landowner/manager's representative.
- Plant seedlings of each species uniformly throughout planting area or as directed by landowner/manager's representative. This is especially important when planting mix species at wide spacing, as planting contiguous areas solely with less hardy species may result in an unacceptably large hole, should the less hardy species experience low survival.
- Micro-site: Where feasible, true fir and Douglas-fir should be planted on the north side of snags, tree stumps, slash, dead brush skeletons and other shade producing objects if available and close to the spot that fits into the spacing pattern. Ponderosa pine can be planted in full sunlight. Examples of micro-siting are shown in Figures 9.4, 9.5, and 9.6.

Figure 9.4 One year after micro-site planting Douglas-fir in the shade of a dead tree (right) and a nearby ponderosa pine planted in full sunlight (left).

Figure 9.5 One year after micro-site planting a Douglas-fir on the north side of a tree stump that provided enough shade during a portion of the day in the previous summer of the first critical year of seedling establishment.

Figure 9.6 Dead brush skeletons also provide suitable shade for Douglas-fir (DF) and white fir (WF) seedlings during the critical first summer growing season after planting. Crews are instructed to plant ponderosa pine in openings and DF and WF in partial shade of dead brush where feasible to reduce direct solar radiant heat on the sensitive basal stems of these species. By the time winter snow crushes down the brush skeletons, the DF and WF seedlings will be sufficiently developed to withstand direct sunlight.

Planting Tools

There are various tools used to plant seedlings with proper methods specific to the tool, seedling stock type and site conditions (i.e. soil, slash, snow, and other dead and live vegetation). Regardless of the tool used, proven methods summarized in Section 8.6.1. must be followed to make sure seedlings are properly planted. Almost all operational reforestation projects in California now use some form of hoedad or shovel to plant seedlings.

Hoedad

By far the most common planting tool used in California is the hoedad (see *Figure 9.7 and 9.8*). This tool is almost exclusively used for planting in the Sierras, Cascades and eastside where relatively small, container grown seedlings are the preferred stock type to plant. When used by well trained and experienced planters on most sites in interior California, the hoedad is the most productive, cost effective, and productive tool for planting seedlings. An experienced planter can average planting more than 1,000 seedlings per day using a hoedad on prepared sites. A hoedad consists of a metal blade typically 3 to 4 inches wide by 16 to 19 inches long that is attached to a 36-inch long wooden handle with a metal bracket that is either angled at 90 degrees (“straight blade”) or at slightly wider bracket angle of approximately 100 degrees (“angled blade”). Due to hand position and mechanics of holding and swinging a hoedad downward when making a planting hole on relatively flat ground, using an "angled blade" makes it easier for the blade to enter the ground at a 90-degree angle (see *Figure 9.7 and 9.8)*. This angle facilitates planting the seedling with the roots straight down and deep rather than at an angle. On steeper slopes however, using a "straight blade" hoedad when planting uphill makes it easier to make a 90-degree hole that facilitates proper placement of the roots. The blade of a hoedad can come in various lengths and shapes, which are selected depending upon the size of the planting stock and/or rockiness of the soil. The effective length of the blade (distance between the tip of the blade and the location of where it is attached to the bracket) should be at least a few inches longer than the length between the root collar and bottom of the roots of the seedlings being planted. It should be long enough such that it can loosen the soil in the planting hole a few inches deeper than where the bottom of the seeding roots will be planted. It should be wide enough to properly break up the soil and open a planting hole that can accommodate the seedling roots. In friable, relatively rock-free soil a longer and wider blade can be used without negatively affecting planting quality, but it could slow down individual planter production or increase fatigue compared to a shorter, narrow bladed hoedad.

A hoedad with a relatively short, narrow blade can be used in surprisingly rocky soil to plant small container grown seedling or even a compact one year old bare-root seedling (see *Figure 9.8).* This is done by holding the "butt" of handle with one hand, or sometimes both hands, very close to the blade and applying pressure to wiggle the blade down between the rocks, deep enough to open a small planting hole. Even if the ground is not too rocky, the use of a shorter, narrower bladed hoedad can facilitate better production without a reduction in quality provided that it can still open a planting hole of sufficient width and depth to properly plant the seedling stock type/size being planted.

Figure 9.7 When planting flat or relatively gentle slopes, the 100-degree angled bracket hoedad (foreground picture on left) facilitates setting the blade into the ground at a right angle easier as shown by the hoedad in the left hand vs. the hoedad with a 90-degree angle bracket causing the planter's right hand to contact the ground when setting the blade at a right angle.

Figure 9.8 Hoedad with a relatively short, narrow blade (left) can be used in surprisingly rocky ground to plant small container grown seedlings (middle). Although the surface is covered almost 100% with rock scree, survival and growth can be excellent due to proper planting technique with the right tool and quality seedlings as shown (right) 2 years after planting on the Moonlight Fire in Plumas County.

Figure 9.9 Hoedad planting starts with using the long side of the blade to "scalp" away (upper left) dry soil, competing vegetation, woody debris, snow, and any other material that must not fall into the planting hole. Next, the hoedad blade is inserted into the ground at right angle (upper right) to a depth at least a few inches below where the end of the seedling roots will be placed; then "breaking out" the planting hole (middle left) by pressing the blade while lifting the top of the handle up and away from the planter such that only the soil between the planter and hoedad blade is loosened and the soil against the bottom side of the hoedad blade is undisturbed. Depending on the soil, sometimes the process of inserting the blade and breaking out the soil is repeated until the blade reaches sufficient depth. Breaking up only the soil between the planter and the hoedad blade allows the planting hole to remain open upon pulling back the hoedad blade in order to place the seedling in the hole properly (middle right). After the seedling is placed in the opening, the hoedad blade is removed so the loosened soil falls back into the planting hole enclosing the seedling in moist, bare mineral soil. The hoedad blade is then inserted at a slight angle approximately 6 inches away from the seedling with the blade tip angled slightly towards the seedling roots so that a slight straightening of the blade as it is pushed towards the seedling will then secure the soil against the seedling leaving no air pockets (lower left). Only a gentle step with the toe of the planter's boot is done to level out the soil around the seedling and make sure there is no loose soil or air pockets around the seedling roots (lower right).

Shovel

A short-handled shovel specifically designed and manufactured for planting or a regular long-handled shovel with footpads of sufficient size and strength can be used in certain situations (see *Figure 9.10*). It can be used for planting in soil that is relatively friable and free of rocks and on well-prepared sites that consist of sufficiently exposed mineral soil such that scalping is not needed. On sites with a lot of slash that limit the effectiveness of hoedad planting, the shovel can be used to plant without scalping. Although rarely used in the Sierra/Cascades/Eastside, shovels are commonly used on the Coast where larger seedlings are typically planted, and sites may consist of heavy slash. In suitable soils shovels can be used to properly plant large two or three-year-old bare-root or plug-1 seedlings more easily than hoedads. However, shovel planting is often less productive and therefore costlier than hoedad planting when the seedling stock type is small and where slash loads are relatively low. In some circumstances, shovel planting might require more site preparation to loosen and expose the soil, such as mechanical "ripping" or sub-soiling, or the use of a separate labor step and tool to scalp to bare mineral soil prior to opening the planting hole.

Commonly used planting shovels are all steel, short handled with "D" shaped grips and handles ranging from 26" to 29" long and attached spades or shanks that are from 12" to 15" long and 6" to 7" wide, and bolt on foot pads that are usually sold separately.

Figure 9.10 Shovel planting steps are similar to hoedad planting which include inserting the shovel blade at right angle to the ground (upper left) to a depth at least a few inches below where the end of the seedling roots will be placed; then "breaking out" the planting hole (upper right) by pressing the top of the shovel handle away from the planter such that only the soil between the planter and shovel blade is loosened and the soil against the front of shovel blade is undisturbed. Breaking up only the soil between the planter and planting spot allows for the planting "hole" to be kept open for proper placement of the seedling upon pulling back the shovel blade (lower left). Then once the shovel is removed, the loosened, friable soil falls back into the planting hole enclosing the seedling in moist bare mineral soil with no air pockets lower right).

Power Auger

Although rarely used in operational reforestation projects, power augers have been used in limited situations such as planting in hard packed soils or soils with a very shallow and thin hardpan layer. Typically, an auger is mounted to a chainsaw type power head and can dig a 4 to 6-inch diameter hole to any depth needed for tree planting (see *Figure 9.11*). However, augers cannot operate on areas with many large rocks and roots. Operator fatigue and maintenance time is typically much higher with a power auger than hoedad or shovel. Also, in heavy clay soils augering can "glaze" the walls of the planting hole restricting future lateral root growth. Thorough scalping prior to making the auger hole is critical to keep dry soil, woody debris, rocks, vegetation and snow from falling into the planting hole. After bare moist mineral soil has been exposed by scalping, it is important to auger the hole perpendicular to the ground surface and in the middle of the scalped area. Care must be taken to power the auger slow enough so that the moist soil is mounded close around the top of the planting hole and not thrown too far away from the hole. After the augered hole is made, the seedling must be planted before any portion of the mounded soil surrounding the hole becomes dry. Therefore, on sunny or dry windy days, the auger operator should do not get too far ahead of the planter. Following these steps will facilitate planting of the seedling with its roots straight down and allow for only moist mineral soil to be placed back in the hole around the roots.

Figure 9.11 Auger Planting Redwood Cultivars.

Machine Planter

Many thousand acres of gentle terrain were machine planted from the 1980's through about 2010 with very good success on private lands in Siskiyou and Modoc counties, California. These projects were primarily on relatively flat ground in areas destroyed by wildfires in the 1970's where stumps had decayed enough so as not interfere with the planting machine. However, with the reforestation backlog caught up on these old burns, this method has not been used in California for several years.

A properly modified machine planter pulled by a small crawler tractor equipped with a V-blade (see *Figure 9.12*) was a very cost-effective method of planting on relatively gentle terrain with suitable soils in old burn sites that had few solid, fresh stumps remaining. Since soils on these sites consisted of live brush roots and decaying tree roots instead of bare plowed soil, the most critical modification made to the manufacturer's planting machine was to replace the trenching tool, i.e. a coulter wheel, with a custom-made cutting blade. This modification allowed for a much cleaner and debris free opening of a planting trench which was critical so that each seedling fed into the trench could be planted properly as the packing wheels then closed the trench. The V-blade attached to the front of the crawler tractor would scalp away a 5 to 6-foot-wide band of grass, brush and woody debris down to moist mineral soil allowing the planting machine attached to the back of the tractor to plant 5,000 to 8,000 seedlings per day. It was a cost-effective method because site preparation of grasses, forbs, and light to moderate sized brush could be accomplished in the same operation as the planting. Unlike piling brush into piles or windrows a substantial distance away from where the trees would be planted, the V-blade left the scalped material within the future rooting zone of the planted trees, providing organic matter to the soil as it broke down. The planting machine, however, was not very efficient at planting wide spacing within a row, as only 8 to 9-foot spacing between seedlings within a row was feasible. Therefore, after early machine planting at high densities resulted in excellent survival rates, typical planting by the mid 1990's consisted of 8 to 9-foot spacing within a row, with rows located 16 to 18 feet apart. Pre-commercial thinning 7 to 10 years later consisted of thinning out every other tree in each row for a resulting density of 135 to 170 trees per acre.

Figure 9.12 A "V Blade" attached to the front of a crawler tractor scalps away grass and brush making a level surface of moist mineral soil (left) in preparation for planting 2-0 bareroot ponderosa pine seedlings by the planting machine attached behind the crawler tractor.

Contracting

Contractor Selection

The selection of the planting contractor is a critical step in the implementation of a successful reforestation project. The increasing importance of having skilled, experienced planters available during a relatively short timing window coupled with increasing reliance on the time sensitive work visa process, means that foresters now plan and secure agreements with planting contractors from several months up to a year prior to planting. Also, experienced reforestation foresters do not limit their criteria in selecting a planting contractor simply to the lowest bidder with the cheapest labor. Compensation necessary to retain skilled, highly motivated planters is critical to ensure careful, proper seedling handling and planting that is necessary for good survival and growth. In addition to cost, the selection of the planting contractor should consider the following: crew, foreman, and contractor experience.

Crew

Successful reforestation foresters have the attitude that the person who actually handles and plants each tree seedling has a very critical role in the reforestation program. They look for indications that members of the crew have expertise, a good work ethic and take pride in their role in a successful reforestation project. Although inexperienced planters periodically join a planting crew and require one on one training, it is important that the majority of the crew consists of experienced, proven planters. It is important to select a planting contractor with a low turnover rate and crew members that are highly motivated. Although training new planters occurs, minimizing turnover and maximizing the use of experienced planters allows the planting contractor's foreman or foremen to focus on the details necessary for the proper organization and oversight of the handling and planting of several thousand seedlings each day. Important questions to ask of a potential planting contractor include:

- What percentage of the planting crew has one full season or more of experience planting?
- What do you do to motivate your planters to produce efficiently and with care and pride in their work?
- What is the average tenure with your company?

Responses to these questions can provide an indicator of how well a planting contractor retains employees that have the expertise and motivation to do quality planting and take pride in their work.

Foreman

The planting crew foreman is critical to a successful reforestation project. Good foremen communicate well with each member of their crew as well as with the reforestation forester, take pride in the work of their crew, and pay attention to detail. They are highly organized and are eager to implement all of the steps necessary for a successful reforestation project. A foreman should be transparent and open with the reforestation forester about problems or potential problems that might arise during planting operations.

Experience, Reputation, and References

This information can be obtained from other experienced reforestation foresters that have used the planting contractor you are considering. A list of reforestation projects completed in the past 5 years can be requested from prospective planting contractors, with a description including the number of seedlings, stock types, planting methods and a list of references (landowners/forest managers/reforestation foresters). Those references should be contacted, and inquiries made as to how they would rate the planting contractor in terms of the criteria listed in this section.

Production & Timing

The planting contractor should have adequate personnel to meet the daily production goals needed to comfortably complete planting within the planting window. Also, the planting contractor must be available to commence planting with sufficient crews and foremen by the date needed. This is very important and should not be overlooked because postponing completion of a planned planting project until the next season usually results in wasted seedlings and the need for additional site preparation of the unplanted area that was scheduled for planting. If one otherwise qualified contractor quotes a cheaper price but cannot guarantee that they will be able to start and complete planting within a suitable timeframe, preference should be given to selecting another qualified contractor that commits to completing on time even if they quote a higher price.

Contractors should be willing to execute a written planting agreement, indemnifying the landowner and/or manager and have adequate commercial general liability and auto insurance naming the landowner and/or manager as additional insured. Contractors should also have workers compensation and employer liability insurance and comply with all state and federal laws and regulations, including but not limited to employment practices, Occupational Safety and Health Administration (OSHA), and environmental laws and regulations. A written agreement should also include terms and conditions that meet the landowner's objectives including enforceable inspection guidelines.

Enforceable Inspection Guidelines

Although enforceable inspection guidelines should be developed based upon the methods and objectives of each specific planting project, the planting contract should list enforceable inspection items that address the steps listed in the 'Essential Steps' subsection in the preceding 'Planting Methods' section.

Production Targets

- Minimum average daily number of trees per crew to comfortably complete the project within the scheduled timeframe. It is understood weather conditions, access, or harsh conditions on particular portions of the planting area might justify planting less than the minimum on some days. However, there should be an overall average daily production target.
- Maximum number of seedlings that can be planted daily per planter to maintain planting quality by minimizing fatigue and short cuts on proper handling and planting techniques. This number depends upon the seedling stock type/size, planting tool, spacing, site, and soil conditions.

Penalties and Incentives

Typical planting agreements specify a minimum percent of seedlings inspected that must have a "satisfactory" rating for all planting criteria, below which the contractor is docked payment. However, if the percent of seedlings inspected that do not pass as satisfactory goes much below this minimum, then the contractor could be held in breach of contract and assessed more severe penalties and possible loss of contract. The forester's daily inspection report can serve as the basis for any payment reduction computed on a daily basis, should such reductions be necessary. Penalties and possibly a breach of contract could also apply to non-compliance with contract terms not related to the inspection of individual seedlings such as improper storage and handling of seedlings in the field, poor distribution of species, failure to meet production targets, and abandonment of seedlings. The excessive abandonment of seedlings (dropped or "stashed" trees) should result in stiff penalties. For example, some planting agreements specify that any tree that is stashed will be paid for by Contractor at 10 times the landowner's purchase price, and that the contractor will not be paid for planting that tree. Tree stashing may be cause, at the sole discretion of the landowner's representative, for immediate suspension of work for the day or termination of the planting contract.

Payment Methods and Rates

There are three general methods of payment to planting contractors. By far the most common method is to pay the contractor based upon the actual number of seedlings planted, usually calculated daily and subject to reduction depending upon contract penalty specifications. This form of payment requires very careful monitoring and documentation of seedling inventories, deliveries to the planting site and seedlings planted on a daily basis. Another method is to pay the contractor based upon the number of acres satisfactorily planted. This requires an accurate calculation of actual acres planted in compliance with the spacing and planting specifications as determined by a sufficient number of sample plots. Although the latter, less common payment method, is a more "turnkey" form of payment, it can cause some logistic challenges in application that could lead to delays in payment, disagreements or uncertainty on the amount of payment. These potential issues may create more risk of uncertainty for the contractor and therefore could lead to higher bids and costs. A third method involving hourly payment is useful in situations where there are significant variables that make it difficult to estimate and then bid or negotiate on a fixed cost per seedling or acre basis. For example, sometimes the planting contractor is paid by the hour each laborer works on a project with many small units and significant travel time required between units. Use of this payment method should be reserved for trusted contractors and agreement on a "not to exceed" amount in the contract, with clear knowledge of crew performance and production levels.

Organizational Needs

Inspectors

If the reforestation forester is overseeing multiple planting projects or a large planting project that requires more than one 10-person crew, trained planting inspectors should assist the forester in administering the planting contracts and in conducting systematic daily planting inspections. A general rule of thumb is to have at least one inspector for every 10 to 14-person planting crew, but in many situations an additional inspector is helpful. If enough inspecting personnel are available, it is a good practice to have one inspector in the field with the crew at all times and one on the landing. The inspector at the landing can also assist in field inspection as the landing duties allow. There are generally two types of inspections (hot v. cold), with "hot" inspection being more common in California, especially on property of small non-industrial landowners. "Hot" inspection involves taking random plots of planted seedlings immediately behind a planting crew and interacting directly with the crew supervisor while the crew is planting. This allows for problems to be corrected in a timely manner and also provides timely direction to the crew supervisor for other matters or questions that might come up. This type of close inspection is preferred when a forester contracts with a planting contractor to plant on several small units and/or several small landowners. The other general type of inspection involves taking "cold" plots after the crew has completed planting a unit with no direct interaction with the supervisor as the crew is planting. The ideal type of inspection and number of inspectors depends upon specific site conditions, size and number of units planted each day, access, and caliber of the planting contractor and planter to foremen ratio. The reforestation forester should conduct a pre-operational meeting with the planting inspectors to train them in the contracted planting techniques, including actual field planting if needed, and to go over all aspects of the planting project including those described in the Seedling Deliveries, Inventory, and Field Considerations sections below.

Seedling Deliveries

Seedling deliveries from the storage location to the planting site via pickup trucks and/or trailers and, if needed, further transport via ATV's, yarders, and/or helicopters must be scheduled and coordinated.

Inventory

It is essential to monitor the rate at which the seedling inventory in the storage facility is being depleted by planting. Sometimes seedlings for a project are not stored at the location from which daily seedlings are loaded. In this situation, seedlings would need to be transported from a separate storage facility to replenish the inventory in the on-site or local cold storage. Planning ahead to anticipate the time required to ship seedlings to the local storage must be factored in to avoid running out of seedlings. A planting contractor without seedlings is not a good situation and may result in losing the contractor to another job during the already short planting window.

Field Considerations

Unit Layout

It may be necessary to identify unit boundaries with flagging, or other suitable means, prior to commencement of planting. Situations where this may be useful include units in which the vegetation control of the site preparation spray is not yet clearly evident, areas where planting will be deferred, and special treatment areas. Identification of unit boundaries ensures that planting crews will not waste time trying to determine the planting area and that seedlings will not be planted outside of the designated planting area.

Maps

Project and unit maps should be readily available on site that show the planting area as well as all access roads. Maps are essential for clear communication with the planting contractor. These maps should be used to document the daily planting progress, unplantable areas, areas requiring additional treatment, etc.

Detailed Unit by Unit Planting Plans

Oftentimes, there may be a different seedling species mix, spacing, or other constraints prescribed for a specific planting unit or within a particular aspect of a planting unit. Consideration of the issues that may be involved with each unit prior to planting and conveying this information to the planting contractor will streamline the planting project. If the planting project has more than one unit or is a large project that can be divided into units, the number of seedlings for each unit should be calculated. Seedlings should be allocated and reserved for each unit to ensure that an adequate number of seedlings are available for the last units to be planted.

Unit Planting Folders

A folder should be available at the cold storage area and landings that include such documents as instructions, unit maps, daily planting inspection and summary forms, and inspection cards.

Trash Disposal

The collection, storage, loading, transport, and disposal of refuse generated from planting should not be underestimated. Often on large planting projects, a substantial quantity of empty seedling boxes, pallets, seedling bags, banding material, and general trash is accumulated. Some seedling nurseries will accept the return of seedling boxes and pallets. The remaining trash must be disposed of by taking to a refuse facility or burned on site if it can be done under safe conditions and if local regulation allows burning of seedling boxes, bags, and pallets.

Pre-operational Meeting

A pre-operational meeting with the reforestation forester, planting inspectors and the planting contractor to discuss the terms of the planting agreement and the logistical and organization aspects relevant to the planting contractor is critical. These pre-operational meetings facilitate much smoother operations because once planting starts, inspectors will be spending long, fast-paced days (often starting a few hours before sunrise and ending well after dark) keeping the planting crews supplied with seedlings, inspecting planting operations, maintaining accurate daily records, and periodic reports.

Planting Inspection

Number of Inspectors per Crew

A minimum of one inspector per 10 to 14-person crew, but in many situations an additional inspector to handle landing duties and assist in field inspections is helpful, especially during the first few weeks of a planting project or planting with a new or inexperienced contractor.

Inspection Procedures

It is important to conduct timely inspections such that problems can be corrected, and adjustments made as soon as possible. Besides the general observations to monitor the planting crew's proper handling of seedlings as previously described, the inspectors should conduct sampling to check on seedling health, spacing, species distribution, micro-siting, and planting techniques (e.g. scalp, depth, root placement etc.). Inspectors should run transects perpendicular to the direction the planting crew has traveled in order to randomly check all planters instead of following one or two planters as the crew progresses. At least 1% of the seedlings should be inspected by first measuring for spacing and then checking to make sure seedlings are not too loose (should not pull up by tugging on a few needles), scalping was adequate, the seedling was planted at the proper depth, and proper planting micro-sites have been selected (if applicable). After checking these items, the inspector should carefully dig up the seedling and check for proper planting angle, roots straight down and not stuffed, no "J" or "L" rooted seedlings, and that all roots are surrounded by moist mineral soil. Dry soil and woody matter that dropped into the planting hole indicates there was no, or poor, scalping prior to opening the planting hole. Air pockets near seedling roots indicate either snow fell into the planting hole (i.e. poor scalp) or the planting hole was not properly closed around the seedling roots.

Documentation

Documentation is critical, such as the use of daily inspection forms (e.g. *Figure 9.13*) made on waterproof paper (if wet conditions are anticipated) with boxes to fill in with symbols indicating satisfactory or unsatisfactory results for each seedling checked. For example, this might be a "0" for satisfactory and if unsatisfactory then a symbol for what criteria was not met (e.g. poor scalp ("S"), loose seedling ("L"), poor angle ("A"), J-root ("J")). The header of each form should include the names of the inspector, contractor, foreman, planting project, and landowner, as well as the date and any other information the forester deems important. There should be a line at the bottom to fill in the number of trees inspected, the number satisfactorily planted, and the percent planted satisfactorily. A place should also be included at the bottom of the form for both the inspector and the crew foreman to sign acknowledging the daily inspection result. Weather proof electronic devices are increasingly being used that document this information along with mapping of daily planting progress.

Tree Information

Daily seedling information should be on the daily inspection form or on a summary form if multiple daily inspection forms are filled out in one day. This should include the number of seedlings planted by nursery/stock type/seedlot and species. Planting inspectors should take the time when loading trees in the morning to count and record the number of seedlings of each lot loaded (by number of boxes and number of seedlings per box). Although it is good practice to plant all seedlings removed from the cooler and transported to the planting site, if there are unplanted seedlings at the end of the day, they should be counted so the net number of seedlings planted is carefully recorded at the end of each day. Of course, any unplanted seedlings should be returned to the cooler at the end of the day and be the first seedlings removed from the cooler and planted the next day. Even though days can be long and hectic, taking the time to accurately keep daily records can greatly benefit accounting later and can be used in tracking progress to schedule timely seedling shipments if more are needed.

DAILY PLANTING INSPECTION FORM

Project ______________________ **Ownership** ______________________
Date ______________________ **Contractor** ______________________
Inspector ______________________

*Nursery	*Species	*Lot	Seedling Owner	# of Boxes	#/Box	# Seedlings Removed from Cooler	# Seedlings Returned to Cooler	*# Seedlings Planted
							Total Planted Today:	

Report results daily to project manager

--*fold here*--

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50

Legend:
O – good tree (ok) H – high tree Lat – high laterals
J – "J" root S – poor scalp T – twisted roots
L – loose tree A - bad angle TD – Too Deep

Other:
Spacing ________ Bag Storage ________
Abnd. Trees ________ ________
Field Storage ________ ________

trees planted satisfactory / # trees sampled = ________ = ________ % acceptable

Notes: ____
____
____
____

Contractor's Signature ____

Figure 9.13 Planting Inspection Form.

Installing Protection Measures in Conjunction with Planting

Although animal pest control measures and mulching are covered more fully in Chapter 8 *Vegetation Management* and Chapter 11 *Damage* respectively, there are a few measures were installation occurs in conjunction with or soon after planting operations, often by the same crews. So, the installation of these materials along with the installation of artificial shading devices are briefly discussed in this sub-section.

Artificial Shading Devices

With proper species and stock type selection, seedling handling and planting practices, including micro-siting, and other methods previously described in this Chapter, the use of artificial shading devices are rarely used. However, occasionally there are certain specific site and species situations where installation of artificial shading devices can improve seedling survival and/or health. For example, shade cards were effectively used in reforesting portions of Cuyamaca Rancho State Park in the arid mountains of southern California after the 2003 Cedar Fire.

The purpose of artificial shading is to protect susceptible seedlings of sensitive species from solar radiation on one or more of the following surfaces:

- The main stem of the seedling that can damage young developing stem surface and kill the underlying cambium.
- The soil surface material that is in direct contact with the seedling stem and root collar and/or close enough to radiate damaging levels of heat.
- The foliage of the seedling that can lead to excessive transpiration, especially on hot, dry sites during the first summer's growing season while the seedling roots are getting established into the soil profile.

In addition to protection from solar radiation, artificial shading devices can also provide protection from the desiccating effects of wind in certain, limited situations.

Ponderosa pine seedlings, even on when planted on harsh sites, are very resilient to the effects of solar radiation and so artificial shading devices are very rarely, if ever, necessary. On certain sites, especially south or east facing aspects, the stems and underlying cambium of Douglas fir (DF) and to a lesser degree, true firs, are susceptible to direct solar radiant heat damage or damage from excessive soil surface temperatures, especially smaller one-year old containerized stock sizes. Relatively larger one-year old DF and fir container stock (Styro 15 or greater) and two or three-year-old bareroot or plug-1 stock not only have more developed, hardened stems but also have more lateral branch foliage to shade the seedling stem and so less need of artificial shading. However, larger stock with more foliage are subject to much more transpiration stress during the critical first year root establishment season on hot, dry sites typical of Southern California and much of interior California, especially on south facing aspects at relatively lower elevations.

Artificial devices are generally comprised of photodegradable, black polyolefin mesh envelope and a wire wicket. They can provide a shade factor of approximately 80% and mesh allows for air passage. The mesh degrades in approximately 5 years and the wire wicket will begin to degrade in approximately 5 years. In most situations where shading devices are used, shading is only needed for the first, and maybe second, year of seedling establishment, when the seedling is developing a root system that is deep and extensive enough to reduce transpiration stress and a hardened stem to protect the cambium and/or lateral branching to shade the seedling stem from direct sunlight. If the devices are only used during the first year or two of seedling establishment, they can be reused until they degrade.

Mulch Materials

Mulch mats manufactured from synthetic fiber, sod, or paper are commercially available or a mulch can be created using bark, pine needles, straw, etc. These mulch products can reduce evapotranspiration from the soil and control competing vegetation. Except in areas where competing vegetation is otherwise controlled or in areas the receive sufficient summer rainfall, mats should cover approximately a 5-foot diameter area around planted seedlings for adequate effectiveness. Mulch mats must be secured to the ground with rocks, stables, spikes, woody debris, etc. It is very important to periodically monitor mats, especially after significant wind events, to ensure that seedlings are not subject to being covered by a mat dislodged by the wind for a period of time sufficient to damage or kill a seedling. The material and installation costs are typically much greater than chemical vegetation control methods and can be cost prohibitive. Mulch mats deteriorate naturally over time but should be removed once they are no longer needed in order to eliminate the risk of wind or other events dislodging the mat and covering the seedling.

Figure 9.14 Properly installed mulch mat.

Animal Pest Protection Materials & Methods

Sometimes in conjunction with planting operations rigid (solid or mesh) protection tubes, mesh netting and/or bud caps are installed if needed to protect newly planted seedlings from animal damage. Installation of seedling protection is generally only used in areas with known pest problems. The cost of the materials and labor are typically as much, or more, than the cost of seedlings and planting. When visiting a planting site to see if it is ready for planting in order to schedule planting crews, a forester can plant several "test" seedlings and monitor them to see if animal damage occurs. Then the forester can be better prepared to arrange for installation of seedling protection devices in conjunction with planting operations. The two most common types of animal damage that can be mitigated by installing protection devices are rabbits which clip small seedling stems at about an inch above ground level and deer that browse the seedling foliage and/or main stem bud and sometimes tear off a very tender main stem:

- Rabbits: Damage is easily diagnosed because rabbits will make a very clean cut of the main stem at a 45-degree angle about an inch above ground level. Since this is done not for consumption of the seedling but simply to keep their teeth from growing too long, the clipped seedling is typically laying close to the tiny "stump". Mostly just small one-year-old container stock early in the growing season are attacked and rarely older seedlings or newly planted two-year old bareroot stock are attacked. One of the most cost effective and maintenance free methods for protecting newly planted seedlings from rabbits (as long as deer browse is not also an issue) is installing plastic mesh buried a few inches below ground level and extending 4 to 6 inches above ground.

- Deer and Elk: The least expensive method to discourage deer browsing is by installing mesh netting, but unlike installation for rabbits, the netting must cover the tops of the seedlings and still allow for seedling growth and/or monitored and maintained through the growing season. This method works best when deer browse is not too heavy and/or temporary for just a few months. For elk or heavy deer browse, plastic mesh tubes anchored with bamboo stakes are more effective. Although more expensive this method is longer lasting and require less maintenance, especially during the first growing season. Although not commonly used in California, the installation of bud caps is a relatively inexpensive treatment for the protection of terminal buds if browsing pressure is limited to the winter and early spring when more palatable forage is not available to deer or elk that might be present on the planting site. Bud caps can be applied prior to spring flush, or in fall after the growing season for overwintering and the following spring. Proper installation can allow for early terminal growth, approximately 2 inches, inside the cap when it is most desirable for the browsing animal. Bud caps should be monitored and removed if terminal growth is negatively impacted by them later in the growing season. Lightweight, degradable mesh bud caps, such as Pacforest Supply Company's "Breath Easy" bud cap can be left to breakdown in most situations but should still be monitored.

Seedling protection tubes and mesh netting are generally not effective against gophers and other burrowing animals.

Figure 9.15 One of the most cost effective and maintenance free methods for protecting newly planted seedlings from rabbits clipping the seedling stems is installing plastic mesh buried a few inches below ground level and extending 4 to 6 inches above ground as shown after planting (left) and at end of first growing season (middle). To protect seedlings from deer browse, the netting must be anchored in soil and extend over the top of the seedling (right) and monitored for maintenance needs.

Figure 9.16 Plastic mesh "tubes" are typically buried a few inches below ground level anchored by bamboo stakes.

Figure 9.17 Solid bud caps installed at a nursery prior to lifting and packing (left). Lightweight, semi-rigid, poly mesh slip on "Breath Easy" bud cap from Pacforest Supply Company applied after planting (middle) to protect seedling from winter deer & elk browse and typically do not need to be removed as shown in second growing season (right).

Planting Follow Up

Stocking Survival Surveys

Systematic, statistically useful surveys to determine first-year seedling survival and vigor and an estimate of seedlings per acre, should be conducted after the first late summer or fall rains. The person conducting the seedling survival surveys should also record conditions of competing vegetation by general type (grass, forbs, and brush) and species of brush and whether or not brush is a germinate (approximate age) or a re-sprout. Also, notes should be taken on any herbicide, insect or animal damage observed in each plot or while travelling between plots. Typical first-year surveys consist of 1/100-acre plots (11.78-foot plot radius) established at 2-chain (132 feet) intervals on 5-chain (330 feet) transects (about 1% of area sampled). The intensity of the sample depends upon the funds and time available and the degree and uniformity of survival after a brief overview. A good first-year stocking survey will aid in scheduling inter-planting, release treatments, or other pest control treatments if needed the following year. Depending upon the results of the first-year stocking surveys and the reforestation forester's experience with the general site and planting stock, a second-year survey might be necessary. Although a systematic survey is not warranted until the end of the first growing season, ocular walk-throughs should be conducted about 2 to 4 weeks after planting which include digging a few trees of each species and stock type to monitor root growth. Additional ocular walk through inspections should occur monthly thereafter until the year-end stocking survey is conducted. These periodic brief inspections are necessary to monitor the health and vigor of seedling foliage, stem, buds, and roots, to evaluate competing vegetation, and to aid in diagnosing any problems if they occur. For example, if seedlings that looked morphologically good were physiologically dead or severely weakened at the nursery or during cold storage they usually will show signs within 2 to 4 weeks after planting. Also, most animal damage problems occur within the first month or two of planting. If there are problems with seedling survival or vigor and if the reforestation forester waits until the end of the season stocking survey to look at the out-planted seedlings, it is much harder to diagnose the myriad of potential causes and at what step it occurred (i.e. at the nursery, storage facility, or after planting on site). Also, early detection and diagnosing could facilitate more timely decisions and actions that could reduce damage and costs.

Figure 9.18 Fall planted WF seedling dug up to check for root development at beginning of next growing season (left). New root growth on PP seedling a few weeks after planting (right).

Figure 9.19 New root growth on Styro 5 containerized Ponderosa Pine seedling two weeks after spring planting in Modoc County with 24" average annual precipitation.

Interplanting

Ocular or systematic stocking surveys may reveal areas that are understocked or non-uniformly stocked. These areas may need to be interplanted to achieve the desired level of stocking and uniformity. The need for interplanting should be carefully considered before committing to it. Sometimes a unit or project may appear understocked and be interplanted only to discover that in 5 to 10 years that the unit is actually overstocked. In this situation, the interplanted trees are often just cut later in the pre-commercial thinning to achieve the desired TPA. Interplanting is more expensive than standard planting due to the time required to find the holes or gaps where seedlings need to be planted. Additionally, the seed transfer, seedling growing, packing, transport, and storage must be accounted for. If interplanting is delayed, an additional site preparatory or release treatment may also be necessary to ensure survival of the interplanted seedlings.

Vegetation and Pest Problem Surveys

As mentioned, plantation surveys can determine the extent of competing vegetation and pest damage. Often a few dead seedlings or competing vegetation can be alarming and lead to the conclusion that treatment is needed. Systematic surveys can be invaluable to quantify the extent and spatial distribution of the damage and aid in determining if treatment is warranted. These surveys can be used as a follow-up to earlier stocking surveys that may indicate the occurrence of problems.

Diagnosing Problems

Periodic monitoring during all phases of the project, including lifting and packing at the nursery, cold storage, transportation to the site, planting and post planting conditions will greatly aid in diagnosing problems that might occur. In addition to monitoring planted seedlings above ground (i.e. seedling stems, branches, needles and buds and presence of competing vegetation) it is very important to dig some seedlings within a few weeks to a month after planting and then in the late summer or early fall excavate the soil around some seedling roots to check on root growth depth and soil moisture availability at rooting depth. In addition to checking on root growth, examining the depth to soil moisture and presence of competing vegetation roots within the seedling's rooting zone in the late summer is a very good indicator of whether or not the competing vegetation was adequately controlled. Even during periodic drought cycles on relatively dry conifer sites, proper vegetation control should provide at the end of summer for sufficient soil moisture within the rooting depth of quality conifer seedlings. What might appear on the surface to be an insignificant amount of competing vegetation and/or an adequate radius of a spot spray or mulch mat treatment, needs to be checked for the presence of adequate soil moisture available to the seedling roots if there is a problem with seedling survival or vigor. The main key to seedling survival in a Mediterranean climate is vigorous root growth down to soil moisture available at the end of the summer. Therefore, checking early season root growth and later checking end of summer root depth and soil moisture are important monitoring techniques for diagnosing problems and prescribing possible treatments. A useful and relatively inexpensive technique to monitor and diagnose potential problems is to plant short "monitoring" rows of each seedling lot at a few different elevations and soil types with labeling that can last at least a few years. Generally, these monitoring rows are planted at convenient locations on the project area, in side-by-side rows of about 20 seedlings of each and at approximately 4 or 5-foot spacing. This can provide a quick, although simple, check for vigor, top, and root growth by seedling lot periodically as the summer progresses. Although a more thorough survey might be needed if problems with a particular stock type, species, and/or nursery arises, the ease of monitoring these rows might alert one earlier to any problem with a particular lot and give a very rough indication of seedling health and vigor by lot. Also, although samples of these trees can be dug up and replanted early in the first season to check for root growth, the close spacing allows for "destructive" sampling to measure root growth at the end of the first and second growing seasons.

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Chapter 10: Precommercial Thinning in California Forests

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Introduction

Precommercial thinning (PCT) can be defined as "*the removal of trees not for immediate financial return but to reduce stocking to concentrate growth on more desirable trees*" (Helms 1998). PCT plays an important part in the reforestation process. It is typically applied between stand establishment and the first commercial thin (CT) or harvest. In addition to altering planting density and competition from non-crop vegetation, selection of which trees remain after PCT affects the timing and average tree size attainable at the next harvest. A higher intensity PCT will shorten the time to grow trees large enough to produce commercial products but will also reduce the total amount of wood fiber (but not necessarily the wood value) available for removal in the first CT.

The decision space for PCT involves:

- Timing (early vs. late PCT)
- Intensity (heavy vs. light PCT)
- Thinning method (selecting favorable trees for retention)
- Implementation (tools and equipment used).

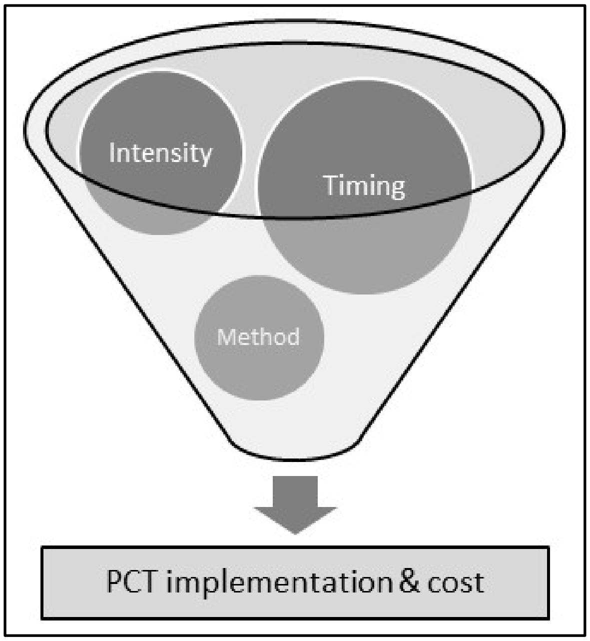

Figure 10.1 PCT timing, intensity, and method affect how it can be implemented and the cost.

PCT influences the risks associated with disturbances such as wildfire (Pollet and Omi 2002), bark beetles (Fettig et al. 2007), windthrow, snow damage (Powers and Oliver 1970) and bear damage. These risks change over time, before/after or with/without PCT. There are occasions where PCT has a role in naturally-regenerated even-aged and multiaged stands, and it is commonly applied in young artificially regenerated (planted) even-aged conifer forests in California.

PCT Outcomes

The decision to conduct PCT comes with the expectation of some outcomes (both positive and negative) for the treatment. We review possible outcomes and how these outcomes are influenced by choices made at the time of PCT implementation.

Enhanced Growth

Thinning results in the redistribution of tree growth to fewer stems, thus increasing growth rates of remaining trees (Ashton and Kelty 2018, p. 395). By accelerating growth rates on residual trees, the time until the retained trees are of a harvestable size is shortened. The increase in tree growth is achieved at some loss to overall stand volume growth per acre and will delay the culmination of mean annual increment (Curtis 1994, 1995).

Growing Stock Improvement

PCT can be a means to improve growing stock. Unhealthy or damaged trees and trees with low vigor or value can be removed. Sometimes the largest trees have poor form and heavy branching. Failure to remove malformed trees at PCT preserves trees that will continue to increase in size but perhaps little in value if logs are defective or become downgraded by large knots.

Growing stock may also be improved by removing species that do not meet management goals. Note that these goals need not be guided by optimal growth. For example, PCT prescriptions could be tailored to maintain and promote trees that provide critical wildlife habitat, like black oak (*Quercus kellogii*). On the other hand, a management goal of maximizing conifer growth and yield would necessarily remove most hardwoods.

Impact on Wood Quality

It is difficult to generalize about the impacts of PCT on wood quality because of differences among species, their end-uses, and innovations in sawmill technology. Maintaining lower stand density will likely produce some degree of reduction in wood quality. Trees with wider spacing can keep low branches alive and growing longer, resulting in low crown base height, larger branch size and knots, lower height-to-diameter ratio and more conical form than trees grown under higher densities (Maguire et al. 1991; Weiskittel et al. 2009; Briggs et al. 2008). These attributes can lead to problems such as downgrading of logs with excessive knot size or reduced recovery of sawn timber from tapered logs. Conversely, postponing PCT keeps lower branches in the shade longer, where they grow slowly or die, and being smaller, these low branches may fall sooner to allow for production of more knot-free clearwood. However, species producing decay-resistant heartwood may be more valuable if they grow rapidly and attain larger log sizes containing more heartwood, while maintaining live lower branches producing inter-grown knots to preserve the integrity of sawn timber for exterior applications (Ashton and Kelty 2018, p. 424). The problem of branches growing unabated into large openings can be mitigated by maintaining evenness of spacing after PCT and reducing the amount of stand edge versus interior stand area where branch size is controlled by contact with neighbor trees.

Enhanced growth after thinning has been linked to changes in wood anatomy and wood product performance in service of some species, but not others. Markstrom et al. (1983) found no impact of growing stock levels in ponderosa pine (*Pinus ponderosa*) on factors linked with performance of structural lumber: specific gravity, latewood percentage, tracheid length or microfibril angle. Rapid diameter growth produces wider annual rings that some consider unsightly, and can have slightly lower specific gravity in some species, e.g., Douglas-fir (*Pseudotsuga menzesii* var *menziesii*) (Jozsa and Brix 1989; Filipescu et al. 2014) and ponderosa pine (Echols 1971). However, the wide rings themselves were not the cause of performance problems. Early PCT promoting rapid diameter growth (and wide rings) at a young age tends to increase the proportion of crown wood in the butt log of conifers (Maguire et al. 1991). Crown wood typically has lower density, stability, and stiffness than outer wood that surrounds it. Therefore we expect better performance from structural lumber sawn from outer wood than from crown wood (Ashton and Kelty 2018, p. 388).

Pruning in concert with PCT can be used to improve wood quality, although the expense limits applicability in many situations. Pruning enhances wood quality and value when branches are removed over an entire log length (e.g., up to 18 feet above ground for a 16-foot log), and this is done early enough to allow clearwood to form over many years after pruning. The economics are more favorable after timely PCT on better sites where rapid *DBH* growth facilitates earlier harvest to recoup pruning costs incurred years earlier. Only a subset of crop trees designated for retention to attain large sizes should be pruned for clearwood timber production. During PCT, additional 'unpruned follower' trees should also be retained to allow for subsequent CTs of knotty sawlogs while pruned trees are allowed to continue growing larger to produce enough clearwood for adequate recovery of knot-free lumber during milling (Ashton and Kelty 2018, p. 432). Pruning can also be done to reduce risk of white pine blister rust (caused by fungus *Cronartium ribicola*) entering lower branches of young pines (O'Hara et al. 2010), or to reduce ladder fuels and facilitate fire suppression efforts in locations such as fuel breaks, high value landscapes, and buffers along main roads. Pruning for forest health or fuels and fire hazard reduction can be restricted to 8-10 feet up from the ground to limit cost, but this restricts clearwood production to an unusually short butt log that may not be saleable at a premium (O'Hara et al. 1995). Pruning for fire hazard reduction is commonly applied strategically within 100 to 200 feet of main roads.

To improve operational efficiency and reduce fuel loading, pruning can be done in 2-3 separate operations or "lifts" conducted a few years apart, leaving 40-50% live crown upon completion of each lift. Pruning heals over better when done on live limbs and not dead limbs, when branches are smaller (smaller wounds) and when trees are growing rapidly (stem encapsulates wound faster). The timing and intensity of PCT and pruning should both be considered when fuel loading is a concern, when the species can suffer from thinning shock (e.g., Douglas-fir and white fir: after PCT, consider delaying pruning), or when the species responds to PCT and/or more severe pruning with epicormic branching that negates benefits of pruning (e.g., coast redwood: leave shade on pruned stem by delaying PCT; O'Hara and Berrill 2009). Timing may be better during the growing season to limit epicormic sprouting (O'Hara et al. 2008), or during the fall and winter to avoid insect attack in some species. A contractor selected for pruning should have the appropriate tools and experience to achieve the desired results.

Insect and Disease Impacts

Density management can also reduce the likelihood of mortality from bark beetles. Low tree vigor is related to bark beetle attacks (Larsson et al. 1983) and thinning has long been proposed as a method to reduce risk of bark beetle attack (Sartwell 1971; Sartwell and Stephens 1975). The primary long-term concern in California will be with *Dendroctonus* species (Table 10.1). While many trees are too small at the time of PCT to be susceptible to *Dendroctonus*, an increase in tree vigor is expected to limit the mortality from bark beetles over time as the trees approach a size where commercial thinning may be considered (Oliver 1995; Fettig et al. 2006, 2007; Egan et al. 2010).

Table 10.1 *Dentroctonus* species of concern for California native conifers

Insect Species	Host Species	Impact
D. brevicomis, Western pine beetle	*P. ponderosa,* *P. coulteri*	Usually attacking trees > 6 inches *DBH*
D. jeffreyi, Jeffrey pine beetle	*P. jeffreyi*	Usually attacks where bole is > 12 inches *DBH*
D. ponderosae, Mountain pine beetle	*P. ponderosa* *P. contorta* *P. lambertiana* *P. monticola* *P. coulteri* *P. flexilis* *P. balfouriana* *P. monophylla* *P. longaeva*	Usually attacks trees > 5 inches *DBH*
D. pseudotsugae, Douglas-fir beetle	*P. menziesii* *P. macrocarpa*	Will infest recent mortality or windthrown trees; can spread to living trees.
D. valens, Red turpentine beetle	*P. ponderosa* *P. contorta* *P. lambertiana* *P. monticola* *P. jeffreyi*	Usually not a tree killer in California, but it may weaken trees; is often active after fire.

Another group of bark beetles that can be a more immediate concern to managers conducting PCT are *Ips* species (Sartwell 1970). The primary species of concern in California are pine engraver (*Ips pini*) and California five-spine ips (*Ips paraconfusus*). Hosts include most pines found in California. Both of these species of *Ips* will readily infect green logging slash, so season of PCT and distribution and amount of slash generated is a concern. Lower levels of slash and more widely scattered slash that dries quickly will tend to inhibit populations of *Ips*. Lopping felled trees may facilitate drying but can be cost prohibitive (cost increases in excess of 50%). In some instances foresters may choose to accelerate drying of felled trees by delimbing the top side to let direct sunlight reach the stem, or leaving the cut tree intact with hope that transpiration via foliage helps purge moisture from inside the stem and branches (Mark Gray, personal communication). Some have suggested that thinning pine in late summer or early fall may also inhibit population growth of *Ips* (Kegley et al. 1997). *Ips* will produce several generations per year and with high levels of slash emerging adults can attack small green trees and the tops of larger trees.

While PCT may improve tree vigor in relation to beetles, it may also exacerbate problems with other insects such as shoot borers (Robertson and Dewey 1983, Ferguson et al. 2011). This problem is most pronounced with heavy thinning removing more than half of the standing trees (Mark Gray, personal communication). Disturbance may also create an environment favoring some root bark beetles, such as *Hylastes nigrinus*, and these beetles can vector black stain root disease (Goheen and Hansen 1993; Hessburg et al. 2001). There is some evidence that host tree species can have different interactions between thinning and root disease. In ponderosa and Jeffrey pine forests, thinning has been observed to reduce occurrence of black stain (Woodruff et al. 2019), whereas thinning in Douglas-fir plantations appears to increase the spread of the pathogen (Harrington et al. 1983; Hessburg et al. 2001).

More generally, the presence of root disease in plantations is not necessarily an impediment to thinning (Filip and Goheen 1995; Filip et al. 2009, 2015). General guidelines for thinning with regard to pathogens are to thin favoring species that are less susceptible to the disease and minimize soil disturbance. Furthermore, care should be taken to avoid spread of pathogens by washing equipment.

Fire and Fuels Management

PCT has the potential to create– through accelerated growth and increased bark thickness– trees of a size that are more resistant to fire (Ryan and Reinhardt 1988; Odhiambo et al. 2014; Zeibig-Kichas et al. 2016). However, in the short-term, trees cut and left on site elevate surface fuels that can increase fire severity. Early implementation when trees and their branches are smaller will reduce this surface load and increase the rate at which slash breaks down. Pruned limbs also become surface fuels that can be scattered or piled to avoid leaving them concentrated at the base of crop trees. Busse et al. (2009) observed that slash fuel load of small material (<7.5 cm in diameter) subsided over a 5-year period. Because of the influence of surface fuels on fire behavior, managers may consider mitigation with chipping or pile and burn treatments. Some PCT prescriptions may call for 'lop and scatter' to minimize fuel concentrations, and reduce the height of fuel beds. Contract language for lop and scatter could simply prescribe a single cut at a specified stem diameter, or prescribe a maximum fuel bed depth to be achieved by cutting fuels into progressively smaller pieces. It is more costly to achieve lower fuel bed depth, but expected benefits include mitigating extreme fire behavior due to faster decomposition of smaller pieces of fuel closer to the ground, where warmth and moisture supports decomposition (Jain et al. 2012, p. 136). However, until lopped surface fuels decompose, they pose a risk of extreme fire behavior (Stephens 1998). Keyes and O'Hara (2002) recommend an integrated strategy combining pruning, low thinning, and surface fuel management to mitigate the risk of crown fire.

Understory Vegetation Development

Lower stand density will encourage the development of understory vegetation including shrubs and herbaceous plants (McConnell and Smith 1970; Thomas et al. 1999; Dagley et al. 2018). Numerous studies show the long-term impact of shrub-competition-induced reductions in growth and yield of conifer trees (Barrett 1973; White and Newton 1988; Oliver 1990; Monleon et al. 1999; Powers and Reynolds 1999; White and Newton 1988; Zhang et al. 2006). For this reason, the growth effects of PCT will be more pronounced when done in concert with effective management of competing vegetation (Barrett 1982; Oliver 1984). For example, a masticator can be used to both thin and masticate brush simultaneously. Effective site preparation and early release treatments will tend to minimize this problem. Alternatively, delayed or repeated light PCT can mitigate this problem by reducing growing space available to understory vegetation.

Thinning Decision Space

Implementation of PCT may involve decisions on method, timing, and density of retained trees, species selection, and selection for size or vigor. In the simplest case of a single-species stand, a non-discriminatory approach such as cutting entire rows of planted trees may be under consideration. With this type of thinning, the decision space concerns only the timing and thinning intensity. However, prescriptions necessarily become more complicated with more discriminatory PCT practices requiring greater levels of understanding by the operator(s).

Timing of Thinning

PCT timing has direct and indirect impacts on cost. In general, PCT in a younger stand is easier and cheaper than culling a more mature stand. Thinning later increases the cost of thinning because trees are larger and therefore take longer to cut and result in more slash (often considered hazardous surface fuels to be dealt with at extra cost). An early PCT will reduce or eliminate the need for slash disposal (Powers et al. 2013). Figure 10.2 shows that early PCT removing 100 to 125 trees per acre when they are 2 inches diameter will generate roughly 1/20th as much biomass and new surface fuels compared to waiting until the trees are 5 inches diameter. Some foresters prefer to wait and conduct PCT when the trees are around 5 inches diameter so that trees have more time to express favorable traits such as superior growth and form. Later PCT also provides more opportunity to remove trees that sustain damage (e.g., bear damage to the stem, or shoot borer/woodrat damage causing forking). However, future dominance may be expressed quite early, allowing for early PCT focused on retaining fast-growing trees. Oliver and Powers (1971) found that ponderosa pine expressed future dominance by the time that trees reach breast height.

For coastal Douglas-fir, Reukema (1975) suggested a thinning window with tree heights between 10-15 feet and age between 10-15 years (Reukema 1975; Reukema and Bruce 1977) on high and medium quality sites. Earlier PCT when the trees are smaller is common in other areas. For example, many forest owners of mixed-conifer forests in California PCT when the stand age is between 7 and 10 years. For pine or pine/Douglas-fir mixtures that are planted at 300 TPA, expect an average site to be ready to PCT in year 7 or 8, whereas high site index areas planted to pine may be ready to thin at year 5 (Mark Gray, personal communication). The rationale for waiting until this time, instead of conducting PCT earlier, is to ensure the crop trees outsize weeds (i.e., unwanted vegetation) such that after PCT the residual trees are capable of quickly re-occupying available growing space instead of prolonging the so-called ‘stand initiation phase’ by ceding more growing space to weeds (Oliver and Larson 1996).

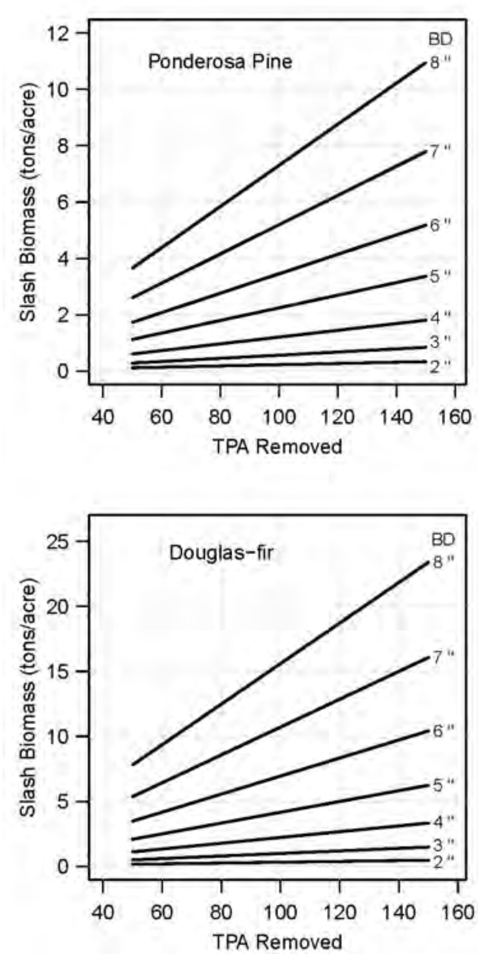

Figure 10.2 Above ground total biomass estimates in tons per acre for thinning slash as a function of average basal diameter (*BD*), at 6 inch stump, of trees removed and the number of trees per acre (*TPA*) to be removed in a precommercial thin; equations from Cochran et al. (1984) and Espinosa-Bancalari and Perry (1987).

Intensity of Thinning

The density of trees (trees acre^{-1}) retained after PCT influences the time at which a first CT may be conducted for any site quality and market. This retention level should be determined by the average tree size in terms of quadratic mean diameter (*QMD*) that a stand should exhibit at the time of CT (Reukema 1975; Webster 1997). As the target *QMD* for CT increases, the residual tree density from PCT should decrease (i.e., grow fewer larger trees). The number of trees per acre and the mean tree size determine the density threshold; density management diagrams (DMD) can guide decisions on PCT residual density for any manager's specific objectives (refer to Density Management section below).

It is a natural tendency for timberland owners and foresters to want to leave stands at higher densities; it can be difficult to cut your own trees or watch thinning crews cut trees you have planted and cared for (Mark Gray, personal communication). However, correct timing and intensity of PCT is an integral step in density management prescriptions designed to maintain the desired balance between rapid individual tree growth (at low stand densities) versus high volume production per acre per year (at higher stand densities).

One recently developed tool that may help in guiding timing and intensity decision making on early stand development of ponderosa pine is OP-Yield (Ritchie and Zhang 2018). This is a spreadsheet adaptation of the Oliver and Powers (1978) yield tables for ponderosa pine plantations (https://www.fs.fed.us/psw/publications/documents/psw_gtr259/) which allows substantial flexibility in evaluating PCT with varying establishment densities and anticipated CT targets. A web application has also been recently produced: http://3.22.183.171:3838/OP_Yield/.

Species Selection

In planted stands, natural regeneration of commercial species such as white fir (*Abies concolor*) or non-commercial species such as tanoak (*Notholithocarpus densiflorus*) can add a considerable number of trees at the point when PCT is planned. PCT provides a window of opportunity to adjust the species mix that will be available at the time of CT and final harvest. Some consideration should be given to the long term development of individual species as early status may not reliably describe future development of the stand. Consider the hypothetical case in Figure 10.3 where tree size exhibits a cross-over effect. In this situation favoring Species A because of an early size advantage may not produce the desired long-term results. For example, nine years after planting at Caspar Creek watershed in Mendocino County, Douglas-fir seedlings were shorter than redwood seedlings which were much shorter than redwood stump sprouts. However, dominant Douglas-fir were expected to overtake dominant redwood in height after a slow start (Jameson and Robards 2007).

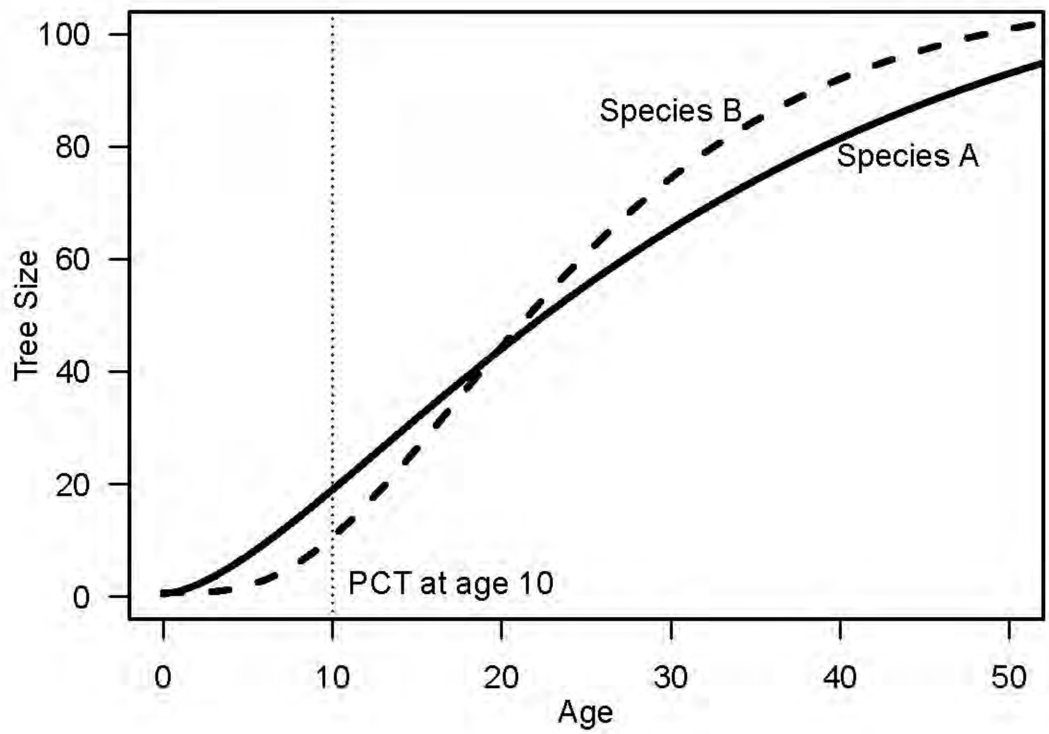

Figure 10.3 Example of different tree-growth forms with cross-over where Species A is larger than Species B at time of PCT (dotted line).

In stands managed primarily for timber production, using PCT to promote evenness of tree spacing is a high priority. Therefore PCT contractors are usually given a target average spacing to aim for, and their success in achieving this goal is assessed by foresters who count residual stems per unit area in small fixed-area plots. In mixed stands, contractors should be provided with species priority for retention, and guidelines on how small the desired species can be before it will be cut instead of a larger neighboring tree of lower species priority. The simplest example is only allowing a lower-priority species to replace a higher priority species when it is “twice as tall”, or “50% taller”, or some such measure that contractors are able to quickly judge. Any such prescription implies that the forester expects the smaller individual tree to be released by PCT and maintain competitiveness until the next stand entry.

Health, Vigor, Form and Defect

Typically, trees selected for retention will be the healthiest and most vigorous. The best trees may not be well distributed throughout the stand and consideration should also be given to the spatial distribution of leave trees. Variability within stands can be handled by ordering or weighting priorities for individual tree retention in the PCT prescription. For example, we might prioritize evenness of spacing, then prioritize tree vigor or size. Straightforward guidelines for contractors give priorities for retention, e.g., “#1: species choice, #2: evenness of spacing, and #3: tree growth and form". Species choice can be listed explicitly, according to individual species names or species groups e.g., "prioritize retention of redwood, then Douglas-fir, then other whitewoods, then hardwoods other than tanoak".

Thinning Methods

The thinning method defines which trees are cut according to their position within the stand, often according to relative tree crown position ranked from highest to lowest: dominant, codominant, intermediate, and suppressed/overtopped. Selecting a defined thinning method helps you refine and communicate your PCT prescription using professional terminology:

- Row thin (also called geometric or mechanical thin; no discrimination based on size; trees from all diameter classes are cut to maintain the same tree diameter distribution),
- Low thin (also called thin from below; focus cutting on smaller trees),
- Crown thin (focus cutting mainly on codominant trees to keep larger trees while also releasing smaller trees with desirable properties),
- Selection thin (also called thin from above or dominant thin; focus cutting on largest trees, which is only acceptable when cut trees were unhealthy or undesirable in terms of species or form),
- Variable-density thin (VDT; cut patches to different spacing, creating a mosaic of different densities throughout the stand, for objectives other than timber production),
- Crop-tree release (CTR; also called localized release; only cut trees in the vicinity of crop trees selected for retention and release from competition), and
- Free-form thinning (situations when any of the thinning methods listed above are deliberately combined for specific objectives).

Row thinning is simple and economical. By felling trees in one direction along a row of plantation trees, row thinning facilitates efficient felling of trees that could otherwise hang up. In dense naturally-regenerated stands, cutting or crushing strips of trees will be simpler and less costly to implement than most other PCT approaches. Row thinning is typically the first thinning in a sequence of planned thinnings (i.e., row thin PCT followed by CTs using more sophisticated thinning methods.

Low thinning reallocates growing space to the largest, most vigorous, and windfirm trees. It preempts natural mortality of weaker trees, but cutting only the smaller trees requires that many trees be cut to achieve the desired release from competition among crop trees. Application in mixed stands can be detrimental when slower-growing species are inadvertently targeted. The small cut trees should decompose more rapidly than relatively larger trees cut during selection or crown thinning.

Crown thinning involves thinning in the middle and upper canopy to create space for promising crop trees of any size. Removing neighboring trees with crowns interfering with crop tree development usually involves cutting codominants, but cutting some dominants or intermediates may also be needed. Crown thinning requires cutting of fewer (larger) trees than low thinning, so it may be more economical and hazardous fuel beds are not as uniform or continuous. In a stand with trees approaching merchantable size, a crown thinning CT could be performed in lieu of a low thinning PCT of the smaller non-merchantable trees.

Selection thinning is used to remove dominant trees of poor health, form, or value such as pioneer species overtopping the desired crop or trees with form problems. Unfavorable genetics may predispose a vigorous tree to form problems such as heavy branching and forking. Also common is stem or leader damage caused by pests damaging the most vigorous trees. Timely PCT that applies selection thinning culls such trees before they overtop desirable crop trees.

Variable-density thinning enhances variability of tree spacing which leads to differences in crown size, growth rate, and tree form within stands. Trees in uncut ‘reserve’ patches grow slowly while other trees grow rapidly at wide spacing and adjacent to patch cuts. This medley of densities is expected to promote development of heterogeneity and complexity characteristic of older forests. VDT is not recommended for timber production because of inefficiencies related to the range of tree sizes and form problems such as heavy branching and crown asymmetry.

Crop-tree release only requires cutting a few large trees with crowns in direct contact with each crop tree. Smaller trees overtopped by the crop tree remain as trainers restricting lower branch growth of crop trees. CTR usually removes crown competition on all four sides of each crop tree, but “3-sided release” can be used to reduce cost albeit at reduced benefit in terms of crop tree growth (Dagley et al. 2018). After localized release of well-formed, desirable trees, much of the stand remains unthinned making the CTR method cost-efficient, especially in dense stands and when low retention densities are prescribed (Leonard et al. 2017).

Free-form thinning combines any two or more thinning methods. Within a plantation, row thinning can efficiently removing entire rows in combination with low thinning along adjacent rows of retention trees to leave a well-spaced stand of superior trees. Free-form thinning is also useful in stands with irregular species composition and structure. Here, the PCT prescription could list different localized conditions matched with the desired thinning method(s). For example, patches of desirable/valuable hardwood or tolerant conifers could receive crown thinning to release them, while areas dominated by intolerant conifers receive low thinning.

For more detail and examples of thinning methods, see Ashton and Kelty (2018, p. 461-485).

Implementation Methods

The options for implementing PCTs include hand treatments, mechanical treatments, chemical treatments, and prescribed fire. Hand treatments (chainsaw, brush-saw or loppers) offer the potential to be very selective but can be slow (and therefore more costly), particularly in stands of advanced age or those with dense competing vegetation. Hand felling allows the land manager to be very specific about which trees to remove and which to leave, enabling the treatment to target problems with disease, insects, mechanical damage or ingrowth of undesirable species. By the same token, this type of PCT can be used to retain and protect or promote growth of critical habitat elements such as snags, mast-producing hardwoods, and trees with features offering habitat value. If possible, the stem should be completely severed below the lowest live branch or foliage, otherwise this foliage may survive and turn upwards to become a replacement stem. The same applies to trees pushed over by other falling trees; the down tree should be cut otherwise its branches may grow upwards as new tree stems that are unstable.

Tree size affects choice of PCT tool. Loppers may be employed for very small diameter trees but often tree size will be prohibitive. Another option for small diameter material (< ~3 inches basal diameter) is a brush-saw or clearing saw. This motorized tool has a blade mounted on a pole, similar to a string trimmer but with a circular saw blade on the cutting end. A clearing saw will not work well for larger trees that require a face-cut, but may prove effective for dealing with dense pockets of natural regeneration. The backpack chainsaw is ergonomically designed specifically for PCT of smaller saplings, with backpack powerhead running a chainsaw bar and chain mounted to the end of a handheld pole. Keyes et al. (2008) reported that when thinning crowded redwood sprout clumps, smaller chainsaws performed adequately and represented a balance between less operator-fatigue from using a larger saw that was slightly faster. Brush-saws and hedge trimmers were not effective because they could not cut larger, older stems (Keyes et al. 2008). Common chainsaw sizes used for PCT are 60-70 cc and power output of 3.5-4.0 kW or 4.7-5.4 hp (Mark Gray, personal communication). Professional grade chainsaws have slightly higher power-to-weight ratio that can reduce fatigue.

Chemical thinning is using herbicides to kill trees selected to be thinned. A common application is to spray unwanted trees that have resulted by seeding in to a planted stand or to spray unwanted species that result from post plant germination of serotinous species such as knobcone pine or lodgepole pine. Spraying can be a useful tool for these young stands, but as the stand grows, spraying is less effective. Hack and squirt application or stem injection of herbicide has been used to thin when the plantation trees reach appropriate thinning age and beyond. With hack and squirt, a small quantity of herbicide is injected/sprayed into cuts (frills) that go through the bark and into the cambium of a target tree.

While most conifer stumps will not resprout after cutting, redwood and most hardwood stumps (Roy 1955) can sprout vigorously in response to thinning. This problem can be solved by spraying a small quantity of herbicide on the freshly cut stump using a handheld spray bottle. Chemical thinning will require a licensed applicator and in-depth knowledge of the best chemical and timing for application. Spring application of chemical injection may be less effective than late season application. There may be a risk of uptake or translocation of some herbicides (e.g., imazapyr) to adjacent crop trees, so testing on a small scale is advisable. Although hack and squirt is most commonly used to remove unwanted hardwoods, it may also prove useful to remove unwanted conifers. Glyphosate, imazapyr and triclopyr will kill most conifers when applied at the proper dose (Mark Gray, personal communication). There are many risks to the remaining stand associated with using herbicides for thinning. For example, imazapyr is readily translocated to adjacent trees of the same species through root grafts and will in many cases damage the tree selected to be the crop tree. Chemical application to conifers doesn’t kill the treated tree rapidly, and some cases only makes the tree decline in health over a long period of time. This can lead to insect outbreaks and increases in disease in an otherwise healthy plantation (Mark Gray, personal communication). Basal bark spraying is another chemical PCT approach where an oil-based penetrant carries the herbicide through the thin bark of young trees. Triclopyr ester is commonly used. This is an efficient way of treating multi-stemmed clumps of resprouting hardwoods quickly with a small amount of herbicide. For more information on chemical weed control, see Tu et al. (2001).

Mechanical chippers or masticators can be used for PCT (USDA Forest Service 2009). They may be boom-mounted or mounted on the front of a wheeled or tracked vehicle. These tools are well suited for row thinning, especially in extremely dense young stands, or thinning in stands of an advanced age, where hand felling will be slow. Mechanized harvesters such as feller-bunchers can cut trees and place them in bundles to be skidded to a landing where the material can be made available to firewood cutters, piled and burned, or chipped and hauled in a chip van to a co-generation plant for production of electric power. In multiaged stands, feller-bunchers can be used to quickly PCT young trees (e.g., dense patches or unwanted species) in conjunction with harvesting of merchantable trees. Operation will be limited by excessively steep or rocky terrain. For more information on mechanical treatments, see Jain et al. (2012).

Another option for PCT is prescribed fire (Windell 1998), although the unpredictability of fire as a thinning tool can induce uncertainty of results. Prescribed fire has been found to be feasible in young plantations (Bellows et al. 2016) when the fire intensity is controlled. Tree mortality can be highly aggregated (Figure 10.4). If conditions are too cool or wet, the fire may not remove enough trees; if too hot and dry it may take out more than desired. Generally speaking, PCT using prescribed fire might be better suited to thinning from below in a stand with larger, older trees that are more resistant to fire.

Probability of surviving fire varies among species and according to season of burn, chances of survival may be slightly enhanced by pruning and raking of fuels away from young trees (Bellows et al. 2016).

Cost Considerations with Precommercial Thinning

Cost of operation will be a key consideration for any PCT project. So, just how much will PCT cost? The problem is that even if we were to produce estimates, they would quickly become obsolete and the costs are significantly influenced by the particulars of a given project. The best approach would be to consult with professionals in your area who have had recent experience with PCT contracting. However, there are some key factors to consider.

The larger the size of the material being cut, the more it will cost (Webster 1997). More so if the contractor will be required to lop and scatter material. Therefore, the longer PCT is delayed, the higher the cost.

The more trees to be cut per acre, the higher the cost of thinning. Thus overplanting a site not only costs you at the time of planting, it will increase the cost of PCT as well. Since it will be decades before one can see a return on investment, this is critical. The time to think about PCT is before you plant.

The equipment used to PCT can also influence cost of operation, and choice of tools depends on size of trees being cut. For example, Jamnick (1989) compared a brushcutter with machete and chainsaw for precommercial thinning of an 8-year old mixed-conifer plantation and found that productivity was lowest with the brushcutter (which might be an efficient tool cutting smaller trees).

Access is another important factor. Is there easy access or will workers have difficulty getting to the site? Any time crews have to walk some distance that will add cost. In like manner, steep slopes will slow productivity and increase costs per acre because workers and machines can generally move more effectively on flat ground. Are there other obstructions to be dealt with like high shrub cover or slash that will slow workers down? Anything that slows the rate of work will increase the cost.

Figure 10.4 Prescribed fire thinning a dense cluster of naturally regenerated ponderosa pine saplings at Blacks Mountain Experimental Forest. *Photo*: Martin Ritchie, US Forest Service.

Density Management

PCT is an important consideration for long-term density management. The ability to manipulate the number and distribution of trees in a stand over time is one of the primary tools of the silviculturist. Stand structure and growth after PCT affects timing of subsequent entries, so a consideration of the general topic of density management is warranted.

We often think about PCT prescriptions in terms of simple metrics of density such as trees per acre (*TPA*) retained. However, as stands develop over time, the metrics necessarily become more complicated and *TPA* no longer adequately describes growing space occupancy in the stand (e.g., 200 *TPA* of small trees occupy less growing space than 200 *TPA* of large trees).

Density Metrics

The generic definition of density is the number of individual trees per acre (*TPA*). For very young plantations, particularly those with fairly uniform survival and distribution, *TPA* will suffice as a descriptor of stand density. In instances where tree survival lacks uniformity as one may find with natural regeneration, *TPA* may need to be augmented with some measure of stocking (Stein 1978, 1992). Stocking reflects the amount of a stand that has been adequately regenerated, often expressed as a percentage. It may be possible to derive estimates of stocking for natural regeneration from estimates of *TPA* (Ritchie 2020).

If we wish to assess development of the stand over time it becomes necessary to incorporate the effect of tree size in any density-related metric, particularly as these expressions relate to growth and mortality. Basal area per acre (*BA*), the cross section of all trees in the stand at breast height (4.5 feet) is one such metric that has been used as a target for late-entry PCT as well as used in later commercial harvests (e.g., Oliver 1979a, 1979b). *BA* can be expressed as a function of quadratic mean diameter (the diameter of a tree of mean *BA* or mean of breast height diameter (*DBH*) squared):

$$BA = k \times TPA \times QMD^2 \qquad (1)$$

Where:

BA = Basal area in square feet per acre,

TPA = Trees per acre,

QMD = quadratic mean diameter in inches, and

$k = 0.005454154 = \frac{\pi}{576} = \frac{\pi}{144\times4}$, a constant needed to convert diameters measured in inches to basal area in square feet.

As an example, if *TPA* is 300 and *QMD* is 3 inches, *BA*=14.7 ft^2 $acre^{-1}$.

One of the more widely applied density metrics, certainly for forests in western North America, is Reineke's Stand Density Index (*SDI*; Reineke 1933). This metric was derived by Reineke for even-aged forests and it takes the general form of:

$$SDI = TPA\left(\frac{QMD}{10}\right)^{1.605} \qquad (2)$$

SDI is indexed to the number of trees in a stand with a *QMD* of 10 inches. The effect of indexing this metric is similar to the indexing of dominant height with site index, wherein dominant height for any given stand is indexed to that of a stand at the base age. With *SDI* values, density is indexed to *TPA* of a stand with a *QMD* of 10 inches. Therefore, if you have two stands with *QMD*s of 7 and 15 inches and both have an *SDI* of 135, both are considered to be at the same level of density in Reineke space; they both are equivalent in density to a stand with a *QMD* of 10 inches and *TPA* of 135. A re-expression of (2) yields:

$$SDI = a \times TPA \times QMD^{1.605} \qquad (3)$$

This expression (where *a*=0.0248) then has a form identical to (1), and one can see that the only important difference, is the value of the exponent on *QMD*. While the exponent of 1.605 is widely applied, it is not universal. Some studies in ponderosa pine have used a value greater than the Reineke (1933) constant of 1.605. Edminster (1988) used 1.66, and 1.7653 was used by DeMars and Barrett (1987) and Cochran (1992). Rounding this to two decimal points yields 1.77, and this has been employed for ponderosa pine as well (Oliver and Powers 1978; Cochran and Barrett 1995; Ritchie and Zhang 2018). As a result, it is important to understand which value is in use for any particular application. The example presented above, of 3 inches *QMD* and 300 *TPA*, yields an *SDI* of 43.

Because Reineke's *SDI* was developed for even-aged stands, it may not be appropriate for uneven-aged or multi-cohort stands. For this reason, some have proposed using a modified version of *SDI* using a summation method (Long and Daniel 1990). The summation form of *SDI* can be expressed as:

$$SDI_s = \sum TPA_i \times \left(\frac{DBH_i}{10}\right)^c \quad (4)$$

where DBH_i is the breast height diameter and TPA_i is the expansion factor, for the *i*th tree in the sample. The exponent, *c*, is the *SDI* exponent, again usually 1.605 although sometimes rounded to 1.6. This expression has the advantage of being additive, so the metric can be compartmentalized by individual tree, size class or species cohort. The two different expressions for *SDI*, (3) and (4) produce metrics that are very close to one another for stands with a symmetric diameter distribution (Curtis 2010; Curtis et al. 2016), as is the case in most plantations. However with multi-modal or long-tailed distributions, the value obtained for *SDI* in (4) can be substantially less than that for (3).

A case can be made for excluding very small trees by setting a minimum diameter limit for calculating (3) or (4), particularly in cases where ingrowth of natural seedlings in the understory is present (Curtis 2010). With regard to Douglas-fir in the Pacific Northwest, the recommendation of Curtis (2010) was to base this restriction on one quarter of the *QMD* of the 40 largest *TPA*, so as to exclude smaller younger trees from the *SDI* calculation. It isn't clear if this method would translate well to other species.

Density Management Diagrams

One approach to decision making with regard to PCT is to first think about an upper limit to density for a managed stand. Observed *SDI* is sometimes divided by the upper limit for that species (SDI_{UL}) to develop a relative density metric (*RD*) bounded by 0 and 1: $RD=SDI/SDI_{UL}$. A value of *RD* near 0.6 is sometimes defined as the upper limit of the management zone (*UMZ*). For example, if the SDI_{UL} is assumed to be 400 and one wishes to establish the *UMZ* at RD=0.6 then *UMZ*=0.6×400=240. Density management would be conducted in such a way as to ensure that the stand will remain below this threshold. Note that this threshold *RD* as well as the SDI_{UL} value may vary by species. The lower limit of the management zone is typically associated with the point where the stand approaches crown closure. So how does a precommercial thinning, which will generally be specified by a TPA or spacing target relate to the *UMZ*? The answer is to first assume a future QMD which will define a stand that can support a commercial entry at some time in the future. For this example, let us assume this is 11 inches. Then we would want to precommercially thin our stand to a level that would assure the stand could reach 11 inches *QMD* without exceeding the *UMZ.* Another way of saying this is that we don't want to reach the *UMZ* until we can enact our next harvest after the PCT, and that harvest should be a commercially viable timber sale. Sticking with this example this is calculated as: $TPA_{pct} = 240(11/10)^{-1.605} = 205.95$. Which is to say, you would want to leave no more than 206 *TPA* in after your precommercial thin.

In this context, density management diagrams (*DMD*) can be helpful in visualizing PCT timing and intensity. Often a *DMD* (e.g. Figure 10.5) is an expression of *SDI* with mean tree size (*QMD*) on the y-axis and *TPA* on the x-axis, both in log-log space. In addition to the lines for fixed values of *SDI*, additional isolines may be included for volume (ft^3 $acre^{-1}$) and dominant height (feet). These can be used to estimate the status of the stand in the future. By assuming a site index system, such as the Biging (1985) curves, one can then also imply the age at a given point in stand development in the DMD space. Other examples of these diagrams are presented later in this chapter.

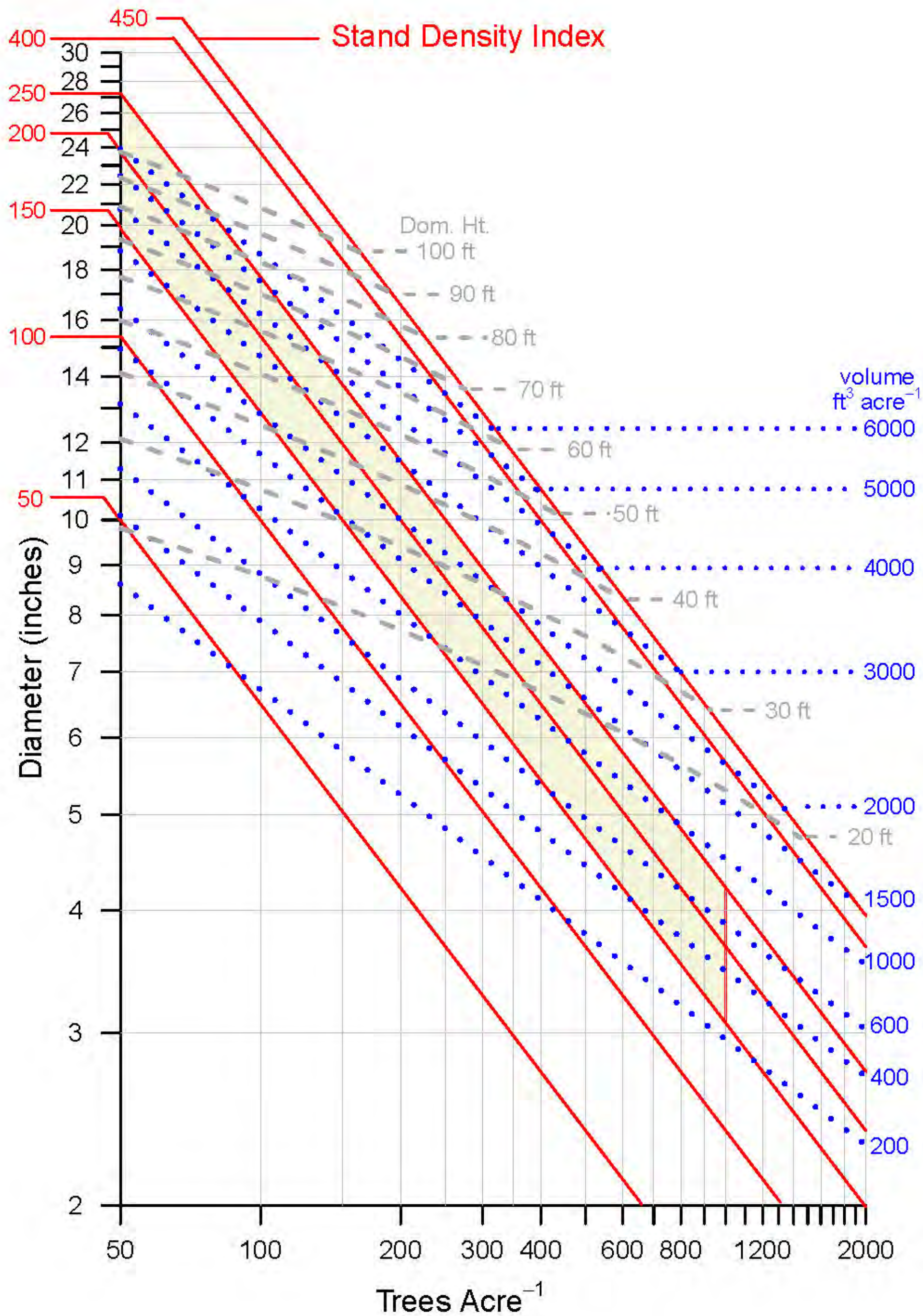

Figure 10.5 Modification of Long and Shaw (2005) density management diagram (*DMD*) with management zone from stand density index (*SDI*) 150 to 250 for ponderosa pine shaded.

Other expressions have been developed for density management. Some present average tree size as mean tree biomass (Drew and Flewelling 1977, 1979). Otherwise, this presentation is very similar. Drew and Flewelling (1979) used relative densities of 0.15 and 0.55 to bound the management zone within which they expect an acceptable compromise between lower densities (fosters individual tree growth and vigor) and higher densities (greater stand growth per acre).

Another common form of DMD employs stand *BA* (e.g. Edminster 1988; Cochran 1992). This approach uses the same technique, deriving a management zone as a proportion of a limiting *SDI*. Edminster's (1988) work on ponderosa pine in the southwestern US and the Rocky Mountains is shown in Figure 10.6.

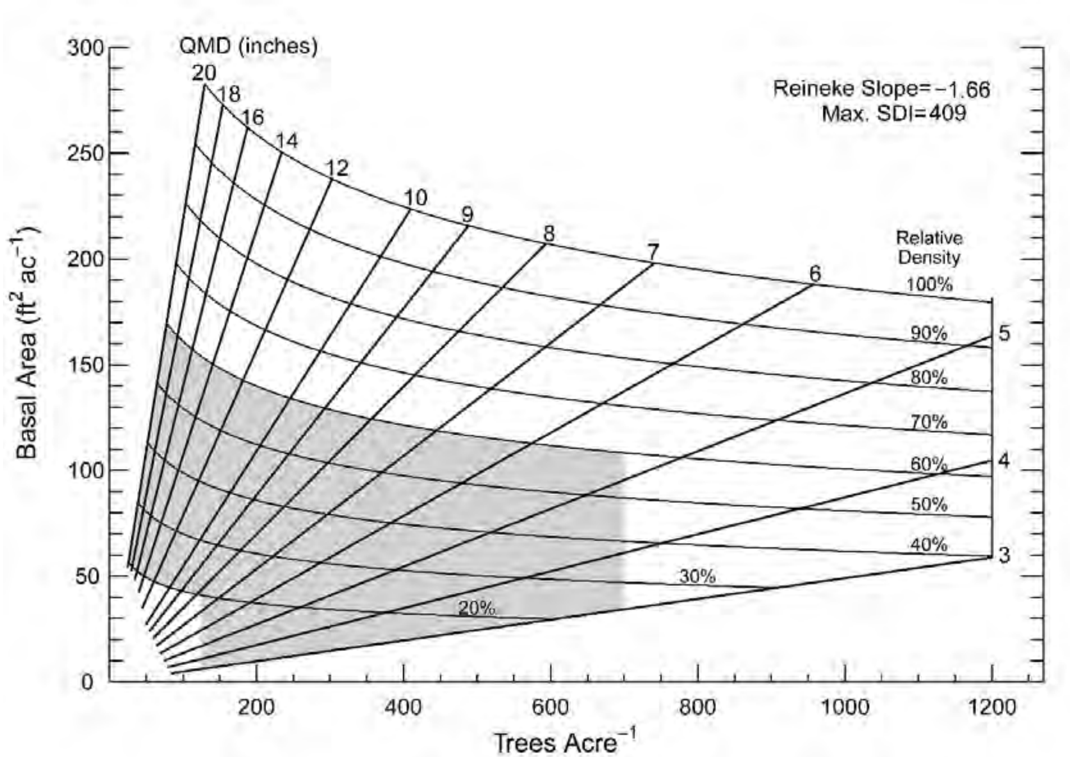

Figure 10.6 Edminster's (1988) density management diagram for ponderosa pine in the southwest and Rocky Mountains, with management zone shaded.

Both types of density management diagrams may be constructed using the *standview* R package, which can currently be accessed within the R computing environment (https://www.fs.fed.us/psw/tools/standview/). The package comes with help files and a vignette providing more detailed guidance on application. A dynamic application of the *standview*, which does not require knowledge of R, can also be found online at http://3.22.183.171:3838/SDMD_PP/.

Relationship between PCT and Establishment Density

To a large extent, planting density drives the need for PCT. High planting densities, or stands with excessive natural regeneration, put stands on a trajectory where PCT will be needed for trees to maintain health and vigor, and reach merchantable size in a reasonable timeframe. Without PCT in these stands, tree growth slows and mortality eventually ensues before reaching a point where CT is possible.

For plantations established after a regeneration harvest, the current California Forest Practice Rules (with recent changes effective January 1, 2020) require achievement of establishment stocking dependent on tree size and site class (Table 10.2). Note that these new standards are substantially lower than those in effect before 2020 and this has an impact on the need for PCT. Successful regeneration is quantified through a point count method where trees less than 4 inches DBH count as one point per acre. Thus if one is counting only small planted or natural seedlings the requisite density is equal to the point count shown in Table 10.2 (California Department of Forestry and Fire Protection 2020, page 36).

Table 10.2 Current (2020) California Forest Practice rules for minimum acceptable stocking (expressed as a point count), by district, after forest operations.

	Site Class				
District	I	II	III	IV	V
Coast	200	200	125	100	100
Northern	125	125	125	100	100
Southern	125	125	125	100	100

With these lower targets it may be possible to skip PCT and get to a CT without having to endure stand conditions that exhibit poor diameter growth and an elevated risk of mortality. Consider a ponderosa pine plantation established with 15x15 foot spacing (194 TPA) and 90% survival. This would produce a point count of about 174 if all trees are no more than 4 inches *DBH*. This would be acceptable stocking on Site III ground (Table 10.2). Without PCT or any subsequent mortality, *SDI* will be about 203 when the stand reaches a *QMD* of 11 inches. This stand remains below the recommended UMZ and therefore could be thinned or allowed to grow longer. For comparison, consider a plantation at 12x12 foot spacing with 90% survival rate. This would produce a point count of approximately 303x0.9=273 if all trees are less than or equal to 4 inches *DBH*. Theoretically, this would produce an *SDI* of 318 when the stand reaches a *QMD* of 11 inches. A site index 100 (at base age 50) stand will achieve this in about 25 years (Oliver and Powers 1978). An *SDI* of 318 is in excess of the suggested *UMZ* for ponderosa pine, indicating that PCT will be needed if one wishes to get to a *QMD* of 11 inches before conducting a CT. Furthermore, any additional natural regeneration will further elevate the *SDI*. PCT reduces *TPA* and *SDI*, allowing trees to attain larger size sooner. Table 10.3 shows the *SDI* associated with various establishment densities (or spacings) at different points of stand development expressed as *QMD*.

Table 10.3 Stand density index (*SDI*) associated with various establishment density (trees per acre; *TPA*) or average tree spacing (ft) and average tree size (quadratic mean diameter; *QMD*) combinations, assuming negligible mortality.

	QMD (inches)											
TPA	8	9	10	11	12	13	14	15	16	17	18	Spacing
50	35	42	50	58	67	76	86	96	106	117	128	29.5
75	52	63	75	87	100	114	129	144	159	176	193	24.1
100	70	84	100	117	134	152	172	192	213	234	257	20.9
125	87	106	125	146	167	190	215	240	266	293	321	18.7
150	105	127	150	175	201	229	257	288	319	352	385	17.0
175	122	148	175	204	234	267	300	335	372	410	450	15.8
200	140	169	200	233	268	305	343	383	425	469	514	14.8
225	157	190	225	262	301	343	386	431	478	527	578	13.9
250	175	211	250	291	335	381	429	479	532	586	642	13.2
275	192	232	275	320	368	419	472	527	585	644	706	12.6
300	210	253	300	350	402	457	515	575	638	703	771	12.0
325	227	274	325	379	435	495	558	623	691	762	835	11.6
350	245	296	350	408	469	533	601	671	744	820	899	11.2
375	262	317	375	437	502	571	644	719	797	879	963	10.8
400	280	338	400	466	536	609	686	767	850	937	1027	10.4
425	297	359	425	495	569	648	729	815	904	996	1092	10.1
450	315	380	450	524	603	686	772	863	957	1055	1156	9.8

As an example, for ponderosa pine at 300 *TPA* and an assumed UMZ of 250, one will reach this point at a *QMD* of about 9 inches. This stand is unlikely to produce a commercial product because the trees are too small. Thus, under earlier regulations, PCT was often not a management option but a silvicultural necessity. Planting densities following a wildfire are up to the landowner, as the California Forest Practice Rules do not dictate stocking for post-fire recovery. Planting a mix heavy to Douglas-fir on a westside stand may also raise the *UMZ* and thus delay the stand's arrival into the zone of imminent mortality (i.e., densities above 0.55-0.6 relative density; Drew and Flewelling 1979, Long 1985).

Regional Considerations

Because there are substantial differences in species and productivity across the state of California, it is important to recognize some regional considerations that may come into play when considering density management of young stands. Managers should also consider localized or emerging issues. Localized issues could include elevated risk of windthrow after heavy late PCT in exposed areas, or risk of large wildfires after creating a continuous fuel bed by conducting PCT over vast contiguous areas. Emerging issues could include elevated risk of loss due to drought in a changing climate prompting PCT to retain fewer *TPA*, or Sudden Oak Death prompting removing hardwoods. Managers may also incorporate language into contracts requiring cleaning of equipment to prevent spread of unwanted seed or fungal pathogens, or actions to be taken in presence of disease such as root rots. For example, in areas with black stain root disease, minimize tree injury during thinning operations, minimize soil compaction, minimize fuel loading, and PCT later in the year after insect flight has occurred (https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5187236.pdf).

PCT in California's Coast Range Forests

Coast range forests are known for their highly productive coast redwood (*Sequoia sempervirens*) forests located on alluvial flats and lower slopes with deep soils and favorable climate moderated by coastal fog. Further inland and upslope, redwood shares growing space with coast Douglas-fir, tanoak, and/or other conifer and hardwood associates eventually giving way to Douglas-fir and tanoak or true oak dominated forests characterized by climate extremes with high vapor pressure deficits. At the southern limits of its range, redwood is found in patches on cooler north-facing slopes where there is sufficient soil moisture for it to survive the hot dry summers. Many efforts to expand redwood's range by planting further inland at higher elevations have so far been successful (e.g., Dagley et al. 2017). It is still unknown whether these redwoods will reproduce by seed to become naturalized or, more likely, just re-sprout from cut stumps. High early survival in these plantations suggests they will benefit from PCT.

After harvesting in Coast Range forests, natural regeneration is usually prolific and can be dominated by less desirable conifers, advance regeneration (i.e., shade tolerant seedlings pre-dating and released by the harvest), and stump sprouts of tanoak and other hardwoods (Thornburgh et al. 2000). Redwood stumps that resprout after cutting can have over 100 sprouts (Neal 1967; Wiant and Powers 1967) that may all die in low light or self-thin when sufficient light is unavailable (O'Hara et al. 2007; O'Hara and Berrill 2010). Jameson and Robards (2007) stated *"…considering that redwoods tend to sprout when cut or destroyed, a high-density planting of redwood, coupled with the naturally high density of native sprouts, may make precommercial thinning more of a necessity than an option to avoid overcrowding and to maintain a reasonable rate of diameter increment… More recently, land managers have begun to reduce the number of trees planted, recognizing that a significant portion of the regeneration will ultimately consist of both redwood sprouts and natural fir seedlings"*.

It is advisable to PCT redwood sprout clumps to promote good growth and form among the best individual sprouts (Boe 1974; Cole 1983; O'Hara et al. 2017). PCT will also provide enough space between sprouts so their stems do not grow together over time and fuse together causing deformities and making future thinning more difficult (O'Hara et al. 2015).

Time and cost of PCT increased with advancing redwood sprout clump size (Keyes et al. 2008). However, an early PCT can stimulate another regeneration event which would be counterproductive. Ingrowth comprised of sprouts arising from stumps cut during PCT as well as prolific natural seedling regeneration may counteract or lessen the benefits of thinning that was originally designed to reduce competition and promote growth of selected trees (O'Hara et al. 2015).

Leaving sprouts originating from the root collar or low down on the stump is recommended since the taller, straighter sprouts located higher on the stump may eventually separate from the decaying stump and topple over. If left unthinned, the process of self-thinning within each sprout clump will proceed, and these tall unstable sprouts will likely come to dominate. Such sprouts have been observed toppling at any age, including up to 100 years of age.

Thinning studies conducted in north coastal California on the Coast Range have included timber management-oriented studies (Oliver et al. 1994; Lindquist 2004, 2007; Webb et al. 2012, 2017; O'Hara et al. 2015) as well as research into thinning for restoration objectives such as directing stand development towards structures resembling old growth forests (e.g., O'Hara et al. 2010, 2012, Teraoka and Keyes 2011; Berrill et al. 2013; Dagley et al. 2018). A long-term study of stand development after PCT to retain 100, 150, 200, 250, 300 *TPA* with unthinned controls continues to yield data as the redwood-dominated stand surpasses a harvestable age of 50 years (Webb et al. 2017). We have learned from this most recent analysis that PCT has a lasting effect on growth in young redwood stands, but that growth is highly variable and sensitive to differences in species composition and small-scale variations in site quality (Webb et al. 2017).

Site quality varies over short distances in redwood forests. Trees in a sheltered gully can be twice as tall as trees on an adjacent ridge and have smaller or greater *DBH* depending on other site characteristics (Berrill and O'Hara 2014, 2015, 2016). Therefore, we might adjust the timing of PCT or residual stand density to best suit patches of forest with similar productivity. If the objective of management were to grow trees of uniform size for commercial harvest at the next stand entry, then in areas of poorer site quality we could PCT to lower densities (wider spacings) to promote individual tree *DBH* growth and PCT to leave higher densities on better areas where trees grow faster to foster more stand production at the expense of *DBH* growth. Similarly, multiaged redwood stands of differing site quality can be expected to have different optimal harvest return intervals, or should have different residual stand densities if the same harvested tree sizes or harvest return intervals are desired (Berrill and O'Hara 2009). PCT in the youngest cohort in multiaged stands will accelerate tree size development and therefore shorten the harvest return interval. It may also lead to harvest of larger trees, provided that sufficient growing space is made available to the understory cohort (O'Hara et al. 2007; Berrill and O'Hara 2009). Cole (1983) noted sprout mortality after early PCT (age 2 years) of redwood sprout clumps in low light; another caution against very early PCT in this forest type. PCT around stand age 10 years is common in redwood/Douglas-fir stands (Figure 10.7).

Figure 10.7 One year after PCT in redwood/Douglas-fir plantation outside of redwood's range with tanoak re-sprouting from cut stumps (above) and light branching after late PCT in pure Douglas-fir that generated deep slash layer (below). *Photo:* Christa Dagley.

Thinning Shock in Douglas-fir

Thinning shock can be a legitimate concern in Douglas-fir plantations (Staebler 1956). Thinning shock is exhibited by a period of reduced height and diameter growth after thinning. The problem seems most acute when thinning is delayed (Reukema 1975) and on poor sites (Harrington and Reukema 1983). The reductions in growth can be quite severe in the short term, but trees will generally recover, resulting in long-term growth increases in response to thinning. DeBell et al. (2002) reported very short lived thinning shock after PCT in a 10 year old plantation in southwestern Washington suggesting that application of PCT early should provide the manager with the best way to avoid it.

Usage of PCT in coastal Douglas-fir has been declining (Talbert and Marshall 2005) because a prevailing view is that Douglas-fir can often make it to CT without the need for PCT. This may be acceptable in a pure stand, but not in mixtures if more desirable species are being outcompeted or in overstocked stands. Suppressed Douglas-fir with smaller crowns are unlikely to respond well to thinning at any age (Tappeiner et al. 2007).

Density Management in Mixed Stands

Setting a goal for tree size (*QMD*) at the next harvest allows us to back-calculate how many trees to retain after PCT. Since redwood tolerates ~67% higher stand density than Douglas-fir (*SDI* upper limits of 1000 and 600, respectively; Reineke 1933), redwood can be retained at tighter spacing than Douglas-fir. In pure stands, 150 *TPA* redwood (17-foot spacing) should reach a 24 inch *QMD* when the stand reaches a *UMZ* of 0.6 relative density (600 *SDI*), but one should only retain 90 *TPA* Douglas-fir (22-foot spacing) if the goal is to reach a 24 inch *QMD* in a timely manner (i.e., when stand reaches *UMZ* of 0.6 relative density for Douglas-fir; Long 1985). Planning a commercial harvest at a lower QMD allows for retention of higher *TPA* at PCT. For example, when planning for a CT once the stand reaches 20 inch *QMD*, the PCT would leave either 120 *TPA* Douglas-fir or 200 *TPA* redwood. This translates into the following prescription for a mixed stand: PCT to leave approximately 19-foot spacing between Douglas-fir trees and 15-foot spacing between redwoods. Subsequently, if 50% of these stems were cut during CT, the remaining stems should have 30 inches *QMD* the next time relative density returns to the *UMZ* in future. Alternatively, cutting fewer than 50% of stems would allow for a shorter harvest return interval, but with smaller harvested tree sizes at the next stand entry.

Thinning in Mixed Stands with Redwood Sprout Clumps

Redwood stump sprouts use their advantage of an established root system to outcompete planted or natural seedling regeneration. Stump sprouts form dense clumps of sprouts surrounding one or more cut stumps associated with the same root system. Depending on the size of the sprouting stump(s) associated with each clump and the size of the entire clump of sprouts, a small clump might be thinned down to one sprout, whereas PCT in a large, multi-stump clump might leave two or three well-formed sprouts spaced 10 feet or more apart. Rather than considering this spacing too tight to meet our objectives for density management, we can compensate by allowing greater spacing between these sprouts and other trees in the vicinity. Our PCT prescription will dictate "spacing off" a certain distance from sprout clumps to allocate the appropriate amount of growing space to each sprout retained in the clump. This can be done by calculating the amount of growing space to be allocated to each clump. If the spacing goal was 17 feet between redwoods (17 x 17 foot = 289 ft^2 growing space), three sprouts should be allocated 867 ft^2 growing space (i.e., 30 x 30 foot square, or a 16.6 foot radius circular area). Adjacent to the growing space allocated to this sprout clump would be growing space allocated to each neighboring tree, so the distance for "spacing off" each redwood clump would depend on the growing space needs of neighbor trees selected for retention. This will depend on species, and if the neighbor is another redwood sprout clump, the number of sprouts retained in that clump.

A simpler approach is to define the tree-size goal for the subsequent stand entry (e.g., 20 inch *QMD*), then prescribe the number of sprouts to be retained per stump (e.g., average two sprouts per clump, range 1-3), and how much growing space will be allocated to each species (e.g., 50:50 redwood:Douglas-fir; note: with this growing space allocation we expect to retain more redwood than Douglas-fir on a *TPA* basis). The PCT prescription then becomes 19-foot average spacing between individual Douglas-fir trees and/or redwood clumps (averaging 2 stems per clump) giving 60 Douglas-fir and 100 redwood for a total of 160 *TPA*, where the redwoods are experiencing higher stand densities in their stump sprout pairs than the Douglas-fir which are well spaced to reach 20 inch *QMD*. Theoretically, the Douglas-fir and redwood stand components should each attain about 20 inch *DBH* and about 0.6 relative density at around the same time. This is because more growing space has been allocated to Douglas-fir versus redwood which can tolerate higher densities. PCT to 15-foot average spacing in a pure redwood stand, or PCT to 16-foot spacing in a redwood-dominated stand, should give trees enough growing space to reach a 20 inch *QMD* at the next stand entry when relative density reaches 60% *UMZ*.

In practice, densities and tree spacings are difficult to control due to the inherent variability in spatial patterns of tree locations in these mixed stands (O'Hara et al. 2015). Deviation from the prescribed spacing to retain better trees will be the norm, requiring the operator to compensate by leaving wider or narrower spacings nearby to meet the overall *TPA* goals. After PCT, higher *TPA* overall will lessen time taken to reach defined *SDI* for CT but at that future time the average tree size will be lower (i.e., harvest smaller trees sooner by retaining more trees at PCT). There is benefit to having a forester present to support contractor decision-making in these complex and variable mixed stands, and to acknowledge and accommodate the variability by prescribing a range of spacing for retention trees. One such PCT prescription accommodates variability by requiring contractors to leave the best tree every 14-20 feet, while clumps are handled differently: leave 2 stems every 10-14 feet or 1 stem every 6-10 feet within the clumps (Mike Alcorn, personal communication).

Reducing Competing Tanoak

Tanoak nuts are an important source of food for wildlife, but tanoak have low to no commercial value so retaining many tanoak per acre may not be advisable. Tanoak compete with conifers and impact their development (Harrington and Tappeiner 2009; Berrill and O'Hara 2014, 2016). Ideally we would treat the tanoak as soon as possible. However, if they are not overtopping the commercial conifers, it may be more efficient and economically advantageous to wait until PCT to remove tanoak. Tanoak also competes with planted and naturally-regenerated young conifers after variable retention and selection harvests (Berrill et al. 2018a, 2018b). Berrill and Han (2017) showed that PCT in group selection openings 10 years after harvest enhanced future growth and yield of merchantable conifers in these openings. The PCT focused on removing hardwood and retaining Douglas-fir and redwood. Berrill and Howe (2019) found that eliminating above- and belowground competition by killing tanoak with herbicide resulted in a major *DBH* growth response in neighboring redwood. Treating tanoak by stem injection, or by spot spraying smaller individuals and clumps, leaves dead wood standing for a time (Krieger et al. 2020). This is generally considered beneficial to mitigate fire hazard as opposed to cutting unwanted hardwoods and leaving the cut biomass as surface fuels (Valachovic et al. 2011). PCT at Headwaters Forest Reserve changed forest structure and fire hazard by increased surface fuel loading and altering the microclimate at the forest floor, resulting in relative humidity lower by 4.6%, and air temperature higher by 1.6°C (Glebocki 2015). The low cost of chemical thinning relative to cutting or girdling makes it an attractive option for a wide range of cull tree sizes.

Thinning Intensity and Bear Damage

Bear damage to conifers is widespread in Del Norte and Humboldt Counties and has been noted further south. Bears strip bark from the tree to feed on sugars in the cambial layer located immediately inside the bark. Perry et al. (2016) found that PCT results in high incidences of bear damage compared to neighboring unthinned stands. Generally, more redwood sustained damage than Douglas-fir. Damage is typically concentrated on larger fast-growing trees (O'Hara et al. 2010; Perry et al. 2016; Berrill et al. 2017; Dagley et al. 2018). Redwoods near forest roads were a little more likely to be damaged than redwoods further inside (Giusti 1990; Hosack and Fulgham 1998; Perry et al. 2016). In light of these results, we might refrain from PCT alongside forest roads, retain higher densities in anticipation of damage, thin small parts of a landscape progressively instead of thinning large areas in hopes that we escape the attention of bears, and/or implement a series of lighter thinnings instead of one heavy PCT that promotes rapid *DBH* growth. When bears damage the young stand before PCT, the PCT prescription should take account for how to prioritize culling trees that sustained damage.

Wood Quality

Heavy PCT encourages branch development, especially on better sites along the Coast Range, as tree crowns quickly expand to re-occupy growing space liberated by thinning. Douglas-fir branches were larger after PCT in Oregon and Washington (Weiskittel et al. 2007), with the largest increase in branch size following low thinning (Maguire et al. 1991). Low thinning removes smaller trees, which often have smaller branches, leaving larger trees with larger branches to re-occupy the growing space. In Mendocino County, branches of overstory trees in multiaged stands responded to partial harvesting (commercial harvest, not PCT) with greater branch basal diameter growth response than after chemical thinning of neighboring tanoak trees, and branch growth response was greater in Douglas-fir than redwood (Kirk and Berrill 2016).

The size, taper, and slenderness of a cut tree influence the number of logs it yields and the size and value of each log. More logs can usually be cut from taller trees. In general, redwood tree height-diameter ratios are lower than Douglas-fir, so Douglas-fir will be taller than redwood of similar *DBH* (Berrill et al. 2012). However, redwoods have a plastic physiology where they can alter their allocation of resources to height growth or diameter growth depending on conditions (Berrill and O'Hara 2016). There is some evidence that taller Douglas-fir encourage neighboring redwood from the same age class to allocate more resources to height growth, presumably to 'keep up with' Douglas-fir or because less *DBH* growth is needed when redwood is sheltered (Berrill and O'Hara 2016). This suggests that frequent light thinning would promote a steadier *DBH* growth rate in redwood when compared against a single heavy PCT that would have long treatment longevity (time until next stand entry) but promote rapid branch growth and *DBH* development.

The timing of thinning influences residual tree growth and form. Over the first five years after PCT at age 2 years in redwood sprout clumps, *DBH* growth but not height growth was enhanced by thinning more intensely (Boe 1974). After this time, both height and *DBH* development were enhanced by the early PCT, but no further benefit was detected after a second PCT at age 15 years (Cole 1983). An alternative to frequent light thinnings or heavy early PCT is to delay the PCT until branches in the first 1-2 logs have become suppressed. Delaying PCT adds to the cost because larger trees are being felled and will tend to hang up, but in the meantime lower branches remain small and many die and fall or break off during the late PCT operation. This may lead to production of valuable knot-free outer wood. Branches may also be removed by pruning. However, we caution that PCT timed to coincide with pruning of lower branches for clearwood production may stimulate a counterproductive epicormic branching response along the pruned bole (O'Hara and Berrill 2009; O'Hara 2012).

Dominant redwoods have higher volume growth efficiency than the lower crown classes (codominants, intermediates, suppressed trees), so cutting the largest most-efficient sprouts on a clump could reduce stand volume production (Berrill and O'Hara 2007). However, this effect may be offset by also cutting the smallest, least-efficient intermediate and suppressed redwoods. Future growth will then be concentrated on well-formed codominant stems adding more valuable wood than small trees with low recovery of sawn timber or on rough large trees with large branches and knots (Plummer et al. 2012; Kirk and Berrill 2016).

Developing a DMD for redwood is problematic due to a lack of data. Reineke (1933) showed a limiting SDI of 1000, although a limit of 774 and an upper management bound of about 550 has been suggested for young stands (Dan Opalach, personal communication). Figure 10.8 shows a DMD for coast redwood with management zone bounded by *RD* of 0.15 and 0.55 (Drew and Flewelling (1979) with an assumed SDI maximum of 1000. When thinning redwood, a narrower density management zone is probably advisable in most cases because thinning from 0.55 to 0.15 *RD* involves removing 73% of the growing stock. This intensity of treatment leaves ample growing space available for brush and is expected to result in transformation to multiaged silviculture by regenerating a vigorous new age class of redwood (Berrill and O'Hara 2009; Berrill et al. 2018b).

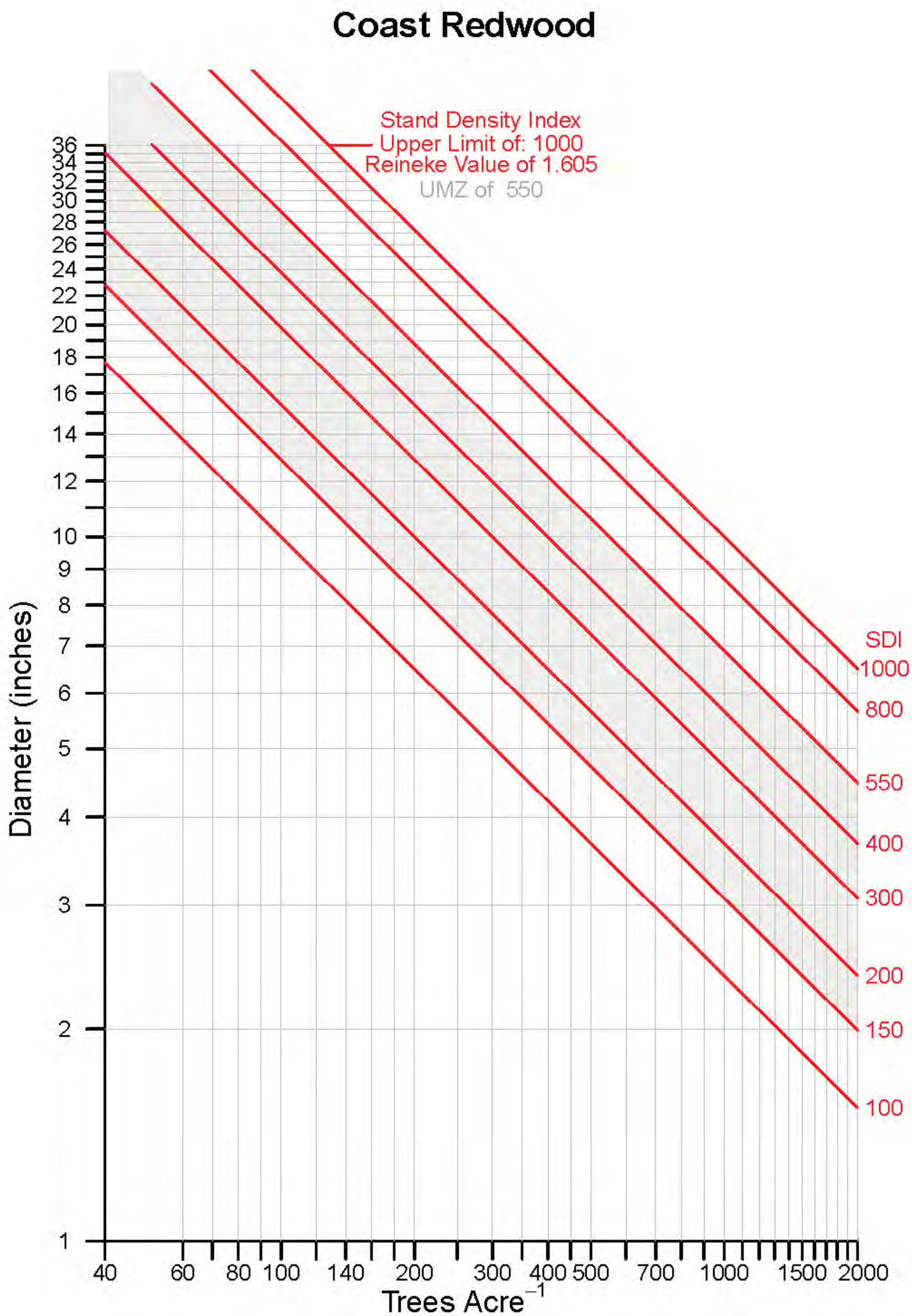

Figure 10.8 Density management diagram for coast redwood forests derived from Reineke (1933) with management zone from Drew and Flewelling (1979).

PCT in California's Eastside Forests

Forests east of the crest of the Cascades or Sierras are drier and colder than westside forests. These eastside forests generally have less than 25 inches total precipitation per year. Due to shorter growing seasons and limited water, forests are less productive than those found in other regions of the state. In an investigation of site classification (Dunning 1942), about 75% of the eastside forests were classified as low in site quality, and average net growth was 104 BF Scribner per acre per year (Bolsinger 1983).

One consideration for precommercial thinning is that rates of slash decomposition are generally slower than those on warmer, wetter sites in California. Thus slash loading is a pressing concern because elevated slash levels will reside longer, producing elevated fire hazard for a longer period of time. Delays in precommercial thinning activity should be avoided so as to minimize the amount of slash and the size of material to be left after PCT. Should PCT be delayed for some reason, it may be necessary to consider slash mitigation measures.

Existing guidelines for PCT in eastside forests dominated by ponderosa pine are few and dated to a period when planting densities tended to be higher. Barrett (1979) reported that even heavy PCT (reduction of 65% *BA*) produced remarkably high volume growth compared to much lighter thinning in central Oregon. Cochran (1983) recommended PCT to 120 *TPA* on a low quality site. Oliver and Trask (1983) found that ponderosa pine responded well after thinning even in stagnated stands. Cochran and Barrett (1999a) in evaluating a spacing study in central Oregon, suggested *TPA* less than 246 for an assumed upper limit of *SDI*=270. This guideline was recommended to minimize long-term risk of mountain pine beetle mortality whereas Cochran and Barrett (1999b) suggested *TPA*=134 (18-foot spacing) for maximizing tree diameter growth.

Density Management of Eastside Forests

Commonly on these dry eastside forests, management efforts focus on ponderosa and Jeffrey pine. Guidelines for management of stand density can vary. Differences among published values for the ponderosa pine *UMZ* (e.g. Table 10.4) serve as a reminder that the *UMZ* is an estimated guideline, not an exact rule; it may also vary dependent on specific management objectives.

Table 10.4 Published upper limit of the management zone for ponderosa pine, with exponent rounded to two decimal places; note some of these are site index (*SI*) dependent with lower SI_{100} (base age 100 years) having a lower stand density index (*SDI*) limit for management; *SI* from Barrett (1978).

Citation	*SDI* Management Limit	Exponent
Oliver (1995)	230	1.77
Edminster (1988)	270	1.66
Long and Shaw (2005)	250	1.60
Cochran et al. (1994)	124 at SI_{100}=70	1.77
Cochran et al. (1994)	161 at SI_{100}=80	1.77
Cochran et al. (1994)	197 at SI_{100}=90	1.77
Cochran et al. (1994)	234 at SI_{100}=100	1.77
Cochran et al. (1994)	270 at SI_{100}=110+	1.77
Cochran and Barrett (1999a)	240-270 at SI_{100}=110	1.77

Cochran et al. (1994) suggest that for poor sites the UMZ should be adjusted as a function of site index, with lower site index being associated with lower target values for the management zone. Consideration of this would necessarily lead one to adjust precommercial thinnings as well because the value assumed for the *UMZ* influences tree retention at PCT. These adjustments of density as a function of site are related to concepts of stockability on marginally productive sites.

As an example application of this figure, suppose that a stand with 300 *TPA* has a PCT at a *QMD* of 3 inches removing 165 *TPA* resulting in an increase in the *QMD* to 3.5 inches (Figure 10.9). This is then followed by a commercial entry when the stand reaches 15 inches (at a dominant height of about 60 feet). At this point the stand will have reached a *UMZ* of 250. The thinning at this point takes the stand back to 79 *TPA* and increases *QMD* to 17 inches, removing approximately 1000 ft^3 $acre^{-1}$ (from 4000 to 3000). Now this thinning from below means that the smaller trees removed will primarily be smaller than the *QMD* of 15 inches. If future market conditions are not favorable or if these trees are too small for a CT, then the landowner will need to wait for a period of time during which some density-related mortality may be experienced as the stand grows past the *UMZ*. Alternatively, a lighter PCT taking the stand back to 200 *TPA* instead of 135 would require a much earlier CT at a smaller *QMD*. A heavier PCT would leave fewer trees that could grow larger before needing to be harvested or becoming overcrowded if *SDI* exceeds the *UMZ*.

In drier, less productive, stands the time between PCT and the first commercial entry will be considerably longer than would be encountered on more productive sites meaning that the return on investment expressed as a net present value is reduced. This means decisions about PCT, or any early cultural treatments during stand establishment can have great impact on profitability. So cost saving efforts early are critical. So on low productive sites, lower planting densities that reduce or eliminate PCT costs should be seriously considered.

It is worth noting that planning based on future CT requires assumptions about the *QMD* associated with a commercially viable timber sale. The assumption of a target tree size comes with some uncertainty. For example, Webster and Fredrickson (2005) recommended a minimum *QMD* of 14 inches for a CT in ponderosa pine. However, fluctuations in market conditions, improvements in milling technology, or even changes in the regulatory environment, could move the minimum tree size that defines a commercial thin.

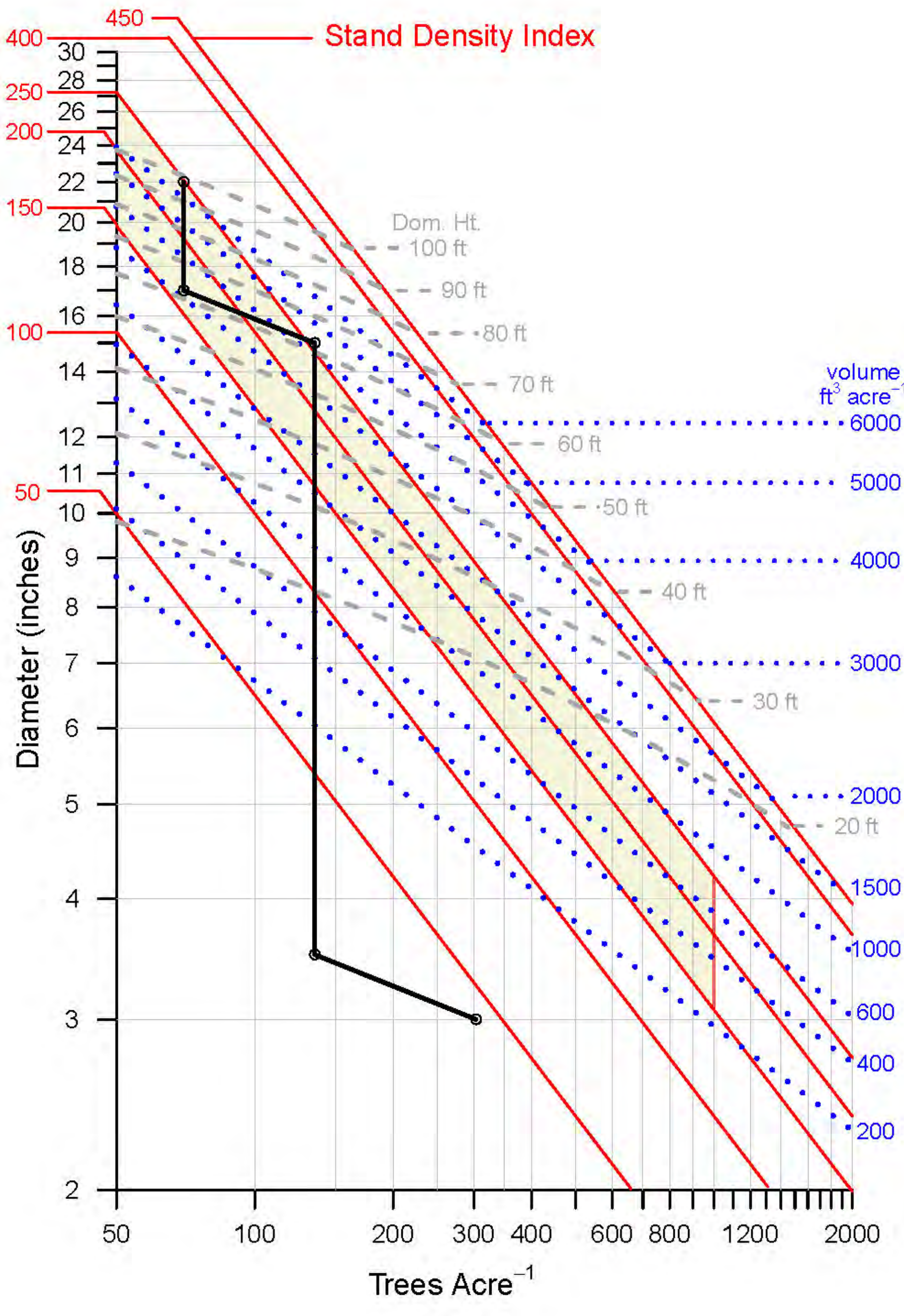

Figure 10.9 Example for ponderosa pine density management diagram from Long and Shaw (2005) with a PCT at 3 inches QMD to 135 TPA, followed by a commercial thin at QMD of 15 inches; estimated volume for commercial thin of ~1000 ft^3 ac^{-1}.

PCT in California's Sierra Nevada and Southern Cascades

In contrast to eastside forests, the mixed conifer forests west of the crest are generally more productive and have greater conifer diversity. Because of greater species diversity, considerations of optimal species mix for planting and retention with PCT become more important.

Managed stands in this range are often comprised of a mix of conifers and hardwoods, most notably black oak (*Quercus kelloggii*) with older plantations dominated by ponderosa pine and Douglas-fir. More recent plantations may include other conifer species in the mix (sugar pine (*Pinus lambertiana*), incense-cedar (*Calocedrus decurrens*), white fir and occasionally giant sequoia (*Sequoiadendron giganteum*), as management philosophy has shifted over time.

Research focused on precommercial thinning in the region is sparse. Some recent research has focused on the role of fire in young plantations (Bellows et al. 2016) and plant diversity (Thomas et al. 1999). Zhang et al. (2013) observed reduced mortality of pine plantations in response to thinning.

Planting practice in the California Sierra Nevada for some time has called for square spacing ranging from 12 to 14 feet, with lower planting densities sometimes used after wildfires in some areas. However, with the new California Forest Practice guidelines allowing lower stocking levels after harvest operations, this is likely to shift toward wider spacing. These wider planting densities after harvest operations on private ground will reduce or in some cases eliminate the need to thin precommercially. This will reduce costs of planting and thinning as well as reduce slash from PCT.

With improved planting stock and vegetation control, survival and growth in plantations has improved over time. This has allowed for dominance and favorable genetic characteristics to be revealed at an earlier age. In the California Sierra Nevada, plantations with heavy components of ponderosa pine are often thinned between 5 and 7 years of age; with mixed species plantations this may be slightly later. Note that there are no guidelines for post fire artificial regeneration, so PCT may not be needed after planting at wide spacing, or it may be needed early in dense patches of natural regeneration.

Density Management of Sierra-Cascades Mixed Conifers

This mix of species necessarily complicates density management since the particular species mix can vary considerably within the region and by ownership. Definition of an upper limit for *SDI* is problematic with any species mix. Reineke (1933) estimated the upper limit for *SDI* in California mixed conifer at about 750, but this value is considerably higher than the value of 550 that Long and Shaw (2012) derived empirically from an analysis of FIA data. Long and Shaw (2012) suggested that the upper limit for mixed-conifer *SDI* should vary dependent on species mix, with values ranging from 524 for a mix of ponderosa and sugar pine to a maximum of 671 for a mix of red fir (*Abies magnifica*) and white fir. Using this method, the actual upper limit for any given stand is a weighted value derived from the particular species mix expressed as a proportion of the stand (Table 10.5). Note that the presence of more shade tolerant species tends to raise the *SDI* upper limit and UMZ. As noted in the previous section this will tend to delay the need for *CT*. Thus the species mix chosen for a given plantation along with the presence of natural regeneration may influence the need for and timing of subsequent thinning.

Table 10.5 Two examples of *SDI* upper limit (*UL*), or limiting *SDI* calculation by taking a weighted mean for California mixed-conifer stands (source Long and Shaw 2012); PP=ponderosa pine, SP=sugar pine, DF=Douglas-fir, WF=white fir, IC=incense-cedar, RF=red fir.

Species	PP	SP	DF	WF	IC	RF	Weighted
UL:	446	561	570	634	576	768	UL
PP-WF	0.40	0.03	0.30	0.20	0.07	0.0	533
WF-RF	0.0	0.03	0.0	0.68	0.0	0.29	671

As previously described, thinning is typically prescribed when stands reach 0.55-0.6 relative density, equivalent to 55-60% of the *SDI* upper limit (*UMZ*). It coincides with the so-called self-thinning line, a value of *SDI* above which the onset of competition-induced mortality increases significantly.

Long and Shaw (2012) gave an example in mixed-conifer where full site occupancy was attained at *SDI* of 200 and then an upper limit for management (onset of self-thinning) was assumed to be at about *SDI* of 300 (Figure 10.10). As an example, if implementing a PCT in a stand with 400 *TPA* at a *QMD* of 3 inches, resulting in a *TPA* of 200 and 4 inches, and assuming minimal mortality thereafter, the stand will reach a *QMD* of 11 inches and *SDI* of about 230. According to this *DMD* (Figure 10.10), the dominant height is about 70 feet at this point. If the site index is 100, then this point will come at about age 35. For site index 80, that point is arrived at about age 45. So if a *QMD* of 11 inches is sufficient for a CT, then a thinning could be possible at this point. There is little risk of mortality since the stand at this point is well below the upper limit for management (300 *SDI*), however it would appear that a PCT to 200 *TPA* may too excessive (i.e., not enough *TPA* retained) if the goal were for CT at *QMD* 11 inches. More volume would be available for CT if the PCT retained 250 *TPA* and the CT could still take place at *QMD* of 11 inches without exceeding the upper limit of 300 *SDI*. If the proposed CT cut down to 150 *TPA* proportional across size-classes (i.e, non-discriminatory row or geometric thinning to leave *QMD* unchanged), then shifting the PCT from 200 to 250 *TPA* resulted in an approximate increase in CT harvest volume from 715 to 1460 ft^3/ac. Thus, CT volume would be doubled in this scenario.

These examples demonstrate how decisions on timing and intensity of PCT can influence the future growth trajectory and future commercial harvests. Site quality should also be considered because optimal PCT age is reached earlier on better sites where height and *DBH* growth is faster. A basic prescription for a Sierra Nevada conifer plantations on medium to high site ground is: plant at 13×13 ft spacing, then PCT to 18×18 at year 6-7, then CT to 28×28 at year 25-30, then let grow to final rotation or subsequent thinning entries. This prescription was developed using the G-space model (Cavallero 1990; Ritchie 1999) which derives thinning schedules using principles of stand density management described above (Mark Gray, personal communication). On poorer sites with slower growth, the thinning would be delayed while on better sites the thinning would be implemented earlier to achieve the desired goal of maximizing growth on high quality trees. Because true fir plantations can thrive at higher stocking levels, a suggested prescription using the G-space model would call for planting at 11x11 ft spacing followed by PCT to 16×16 ft at year 10, then some time later CT to 22×22 and grow to rotation or extend the time until final harvest by implementing a second CT to 31×31 ft average spacing (Mark Gray, personal communication).

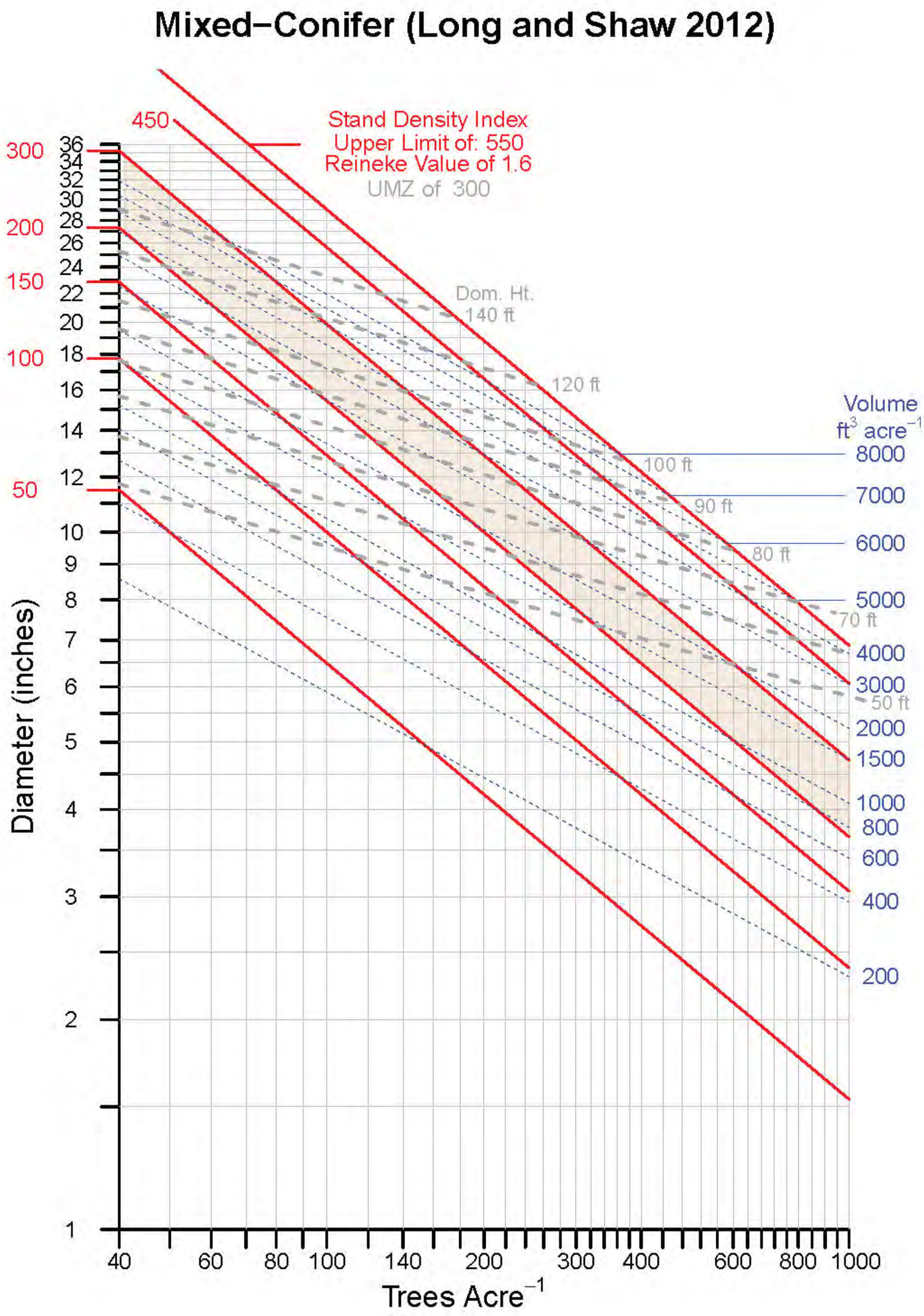

Figure 10.10 Density management diagram for California mixed-conifer forests derived from Long and Shaw (2012).

Summary

The need for PCT is driven by planting density. If we plant fewer trees, the need for PCT may be eliminated. The most current (2020) California Forest Practice rules have reduced stocking requirements and provide for greater decision space in this regard. When managing toward wider tree spacing, effective management of competing vegetation becomes even more critical, as nature will often attempt to fill that space with competing vegetation that will lower tree growth rates and increase fuel loading.

PCT leads to stand improvement by culling less desirable trees, but properly identifying favorable trees early in stand development may be problematic. Delaying PCT will increase the cost of thinning and increase fuel on the forest floor, but may be desirable in some situations, (e.g., waiting for canopy closure to shade out weeds, or where we expect bears to damage young trees growing rapidly after PCT, or in markets where lumber with narrow growth rings or smaller knots commands a premium price). We provided information and guidelines to support the manager's decision making, but these are not hard-and-fast rules. Tradeoffs abound in the manager's PCT decision space. If the objectives of management are to maintain wide spacing between trees (e.g., to reduce drought stress or fire hazard), this is achieved by adopting lower density targets (*UMZ*). Higher rates of tree growth will be sustained due to reduced competition, and the trees may better resist insect attack, but wood production on a per-acre basis will be sacrificed.

Conversely, allowing stands to surpass relative densities of 0.55-0.6 is expected to enhance wood production per acre, but with elevated tree mortality. This could prolong the time taken for trees to reach merchantable size and put the crowded stand at greater risk of stand-replacing fire, or forest health problems from reduced tree vigor; self-thinning will ensue as competition intensifies.

The environment in which thinning takes place is dynamic in many respects. Technological improvements providing for better seedling quality or tools and techniques that enhance early growth and survival of planted stands may influence the need for PCT. By the same token, changing market conditions or shifts in the regulatory environment could impact all phases of forest regeneration and it is difficult to anticipate how that may influence decisions regarding the implementation of PCT thinning in the future. Foresters need to be attentive to such changes and current research in order to make timely and effective decisions regarding density management in California forests.

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References

Ashton, M.S., and M.J. Kelty. 2018. The Practice of Silviculture: Applied Forest Ecology. 10th Edition. John Wiley & Sons. 776 p.

Barrett, J.W. 1973. Latest results from the Pringle Falls ponderosa pine spacing study. Res. Note PNW-209. USDA For. Serv. PNW For. and Range Exp. Stn. Portland OR. 22 p.

Barrett, J.W. 1978. Height growth and site index curves for managed even-aged stands of ponderosa pine in the Pacific Northwest. Res. Pap. PNW-232. USDA For. Serv. PNW For. and Range Exp. Stn. Portland OR. 14 p.

Barrett, J.W. 1979. Silviculture of ponderosa pine in the Pacific Northwest: The state of our knowledge. Gen. Tech. Rep. PNW-97. USDA For. Serv. PNW For. and Range Exp. Stn. Portland OR. 106 p.

Barrett, J.W. 1982 Twenty-year growth of ponderosa pine saplings thinned to five spacings in central Oregon. Res. Pap. PNW-301. USDA For. Serv. PNW For. and Range Exp. Stn. Portland OR. 18 p.

Bellows, R.S., A.C. Thomson, K.J. Helmstedt, R.A. York, and M.D. Potts. 2016. Damage and mortality patterns in young mixed conifer plantations following prescribed fires in the Sierra Nevada, California. For. Ecol. Manage. 376:193-204.

Berrill, J-P., and H-S. Han. 2017. Carbon, harvest yields, and residues from restoration in a mixed forest on California's Coast Range. For. Sci. 63(1):128-136.

Berrill, J-P., and R.A. Howe. 2019. Multiaged redwood responds well to partial harvest and herbicide treatments. Can. J. For. Res. 49(11):1425-1433.

Berrill, J-P., and K.L. O'Hara. 2007. Patterns of leaf area and growth efficiency in young even-aged and multiaged coast redwood stands. Can. J. For. Res. 37(3):617-626.

Berrill, J-P., and K.L. O'Hara. 2009. Simulating multiaged coast redwood stand development: Interactions between regeneration, structure, and productivity. West. J. Appl. For. 24(1):24-32.

Berrill, J-P., and K.L. O'Hara. 2014. Estimating site productivity in irregular stand structures by indexing basal area or volume increment of the dominant species. Can. J. For. Res. 44(1):92-100.

Berrill, J-P., and K.L. O'Hara. 2015. Spatial variation in dominant height and basal area development in a coast redwood forest: implications for inventory and modeling. J. Biodiv. Manage. and For. 4(4):1-6.

Berrill, J-P., and K.L. O'Hara. 2016. How do biophysical factors contribute to height and basal area development in a mixed multiaged coast redwood stand? Forestry 89:170–181.

Berrill, J-P., J.L. Jeffress, and J.M. Engle. 2012. Coast redwood live crown and sapwood dynamics. Pp. 473-484 in Standiford, R.B.; Weller, T.J.; Piirto, D.D.; Stuart, J.D. (Tech. Coords.). Proc. of Coast redwood forests in a changing California: a symposium for scientists and managers. Gen. Tech. Rep. PSW-GTR-238. USDA For. Serv. PSW Res. Stn. Albany, CA. 675 p.

Berrill, J-P., C.B. Beal, D.H. Lafever, and C.M. Dagley. 2013. Modeling young stand development towards the old-growth reference condition in evergreen mixed-conifer stands at Headwaters Forest Reserve, California. Forests 4(2):455–470.

Berrill, J-P., D.W. Perry, L.W. Breshears, and G.E. Gradillas. 2017. Tree size, growth, and anatomical factors associated with bear damage in young coast redwood. Pp. 326-328 *In:* Standiford, R.B., and Y. Valachovic (Tech. Coords.). Proceedings of coast redwood science symposium—2016: Past successes and future direction. Gen. Tech. Rep. PSW-GTR-258. USDA For. Serv. PSW Res. Stn. Albany, CA. 446 p.

Berrill J-P., Dagley, C.M., Gorman, A.J., Obeidy, C.S., Powell, H.K., and J.C. Wright. 2018a. Variable-density retention promotes spatial heterogeneity and structural complexity in a Douglas-fir/tanoak stand. Current Trends in Forest Research. CTFR-108 DOI: 10.29011/CTFR-108. 100008.

Berrill, J-P., Schneider, K.A., Dagley, C.M., and L.A. Webb. 2018b. Understory light predicts stump sprout growth in mixed multiaged stands in north coastal California. New Forests 49(6):815–828.

Biging, G.S. 1985. Improved estimates of site index curves using a varying-parameter model. For. Sci. 31:248-259.

Boe, K.N. 1974. Thinning promotes growth of sprouts on old-growth redwood stumps. Res. Note PSW-290. USDA For. Serv. PSW For. and Range Exp. Stn. Berkeley, CA. 5 p.

Bolsinger, C.L. 1983. An overview of forest resources and trends in the eastside pine type of California. Pp 29-38 *In*: Robson, T.F., and R.B. Standiford (Editors). Management of the eastside pine type in northeastern California. Proceedings of a Symposium June 15-17 1982. SAF-83-06, Northern California Society of American Foresters.

Briggs, D.G., R. Kantavichai, and E.C. Turnblom. 2008. Effect of precommercial thinning followed by a fertilization regime on branch diameter in coastal United States Douglas-fir plantations. Can. J. For. Res. 38:1564-1575.

Brix, H. 1981. Effects of thinning and nitrogen fertilization on branch and foliage production in Douglas-fir. Can. J. For. Res. 11:502-511.

Busse, M.D., P.H. Cochran, W.E. Hopkins, W.H. Johnson, G.M. Riegel, G.O. Fiddler, A.W. Ratcliff, and C.J. Shestak. 2009. Developing resilient ponderosa pine forests with mechanical thinning and prescribed fire in central Oregon's pumice region. Can. J. For. Res. 39:1171-1185.

California Department of Forestry and Fire Protection. 2020. California Forest Practice Act Rules. Title 14 California Code of Regulations Chapters 4, 4.5 and 10.

Carlton, D.W., and S.G. Pickford 1982. Fuelbed changes with aging of slash from ponderosa pine thinnings. J. For. 80:91-107.

Cavallaro, J. 1990. An organismal level process model for simulating tree and stand growth responses to thinning. Pp. 207-216 *In*: Wensel, L.C., and G.S. Biging (Technical Editors). Forest simulation systems, proceedings of the IUFRO conference; 1988 November 2-5; Berkeley CA. Bulletin 1927 Division of Agriculture and Natural Resources, University of California.

Cochran, P.H. 1983. Implications of site quality for eastside ponderosa pine. Pp. 59-65 *In*: Robson, T.F., and R.B. Standiford (Editors). Management of the eastside pine type in northeastern California. Proceedings of a Symposium June 15-17 1982. SAF-83-06, Northern California Society of American Foresters.

Cochran, P.H. 1992. Stocking levels and underlying assumptions for uneven-aged ponderosa pine stands. Res. Note PNW-RN-509. USDA Forest Service PNW Res. Stn. Portland OR. 10 p.

Cochran, P.H., and J.W. Barrett. 1995. Growth and mortality of ponderosa pine poles thinned to various densities in the Blue Mountains of Oregon. Res. Pap. PNW-RP-483. USDA For. Serv. PNW Res. Stn. Portland OR. 27 p.

Cochran, P.H. and J.W. Barrett. 1999(a). Thirty-five year growth of ponderosa pine saplings in response to thinning and understory removal. Res. Pap. PNW-RP-512. USDA For. Serv. PNW Res. Stn. Portland OR. 28 p.

Cochran, P.H., and J.W. Barrett. 1999(b). Growth of ponderosa pine thinned to different stocking levels in central Oregon: 30-year results. Res. Pap. PNW-RP-508. USDA For. Serv. PNW Res. Stn. Portland, OR. 27 p.

Cochran, P.H., J.M. Geist, D.L. Clemens, R.R. Clausnitzer, and D.C. Powell. 1994. Suggested stocking levels for forest stands in northeastern Oregon and southeastern Washington. Res. Note PNW-RN-513. USDA For. Serv. PNW Res. Stn. Portland, OR. 21 p.

Cochran, P.H., J.W. Jennings, and C.T. Youngberg. 1984. Biomass estimators for thinned second-growth ponderosa pine trees. Res. Note PNW-415. USDA For. Serv. PNW Res. Stn. Portland, OR. 6 p.

Cole, D.W. 1983. Redwood sprout growth 3 decades after thinning. J. For. 81(3):148–150,157.

Curtis, R.O. 1994. Some simulation estimates of mean annual increment of Douglas-fir: Results, limitations, and implications for management. Res. Pap. PNW-RP-471. USDA For. Serv. PNW Res. Stn. Portland, OR. 27 p.

Curtis, R.O. 1995. Extended rotations and culmination of age of coast Douglas-fir: Old studies speak to current issues. Res. Pap. PNW-RP-485. USDA For. Serv. PNW Res. Stn. Portland, OR. 49 p.

Curtis, R.O. 2010. Effect of diameter limits and stand structure on relative density indices: A case study. West. J. of Appl. For. 25:169-175.

Curtis, R.O., B. Sheel, and C.A. Harrington. 2016. Relation of initial spacing and relative stand density indices to stand characteristics in a Douglas-fir plantation spacing trial. Res. Pap. PNW-RP-607. USDA For. Serv. PNW Res. Stn. Portland, OR. 27 p.

Dagley, C.M., J-P. Berrill, F.J. Johnson, and L.P. Kerhoulas. 2017. Adaptation to climate change? moving coast redwood seedlings northward and inland. Pp. 219-228 *In:* Standiford, R.B., and Y. Valachovic (Tech. Coords.). Proceedings of coast redwood science symposium—2016: Past successes and future direction. Gen. Tech. Rep. PSW-GTR-258. USDA For. Serv. PSW Res. Stn. Albany, CA. 446 p.

Dagley, C.M., J-P. Berrill, L.P. Leonard, and Y.G. Kim. 2018. Restoration thinning enhances growth and diversity in mixed redwood/Douglas-fir stands in northern California, USA. Restoration Ecol. 26(6):1170-1179.

DeBell, D.S., C.A. Harrington, and J. Shumway. 2002. Thinning shock and response to fertilizer less than expected in young Douglas-fir stand at Wind River Experimental Forest. Res. Pap. PNW-RP-547. USDA For. Serv. PNW Res. Stn. 20 p.

DeMars, D.J., and J.W. Barrett. 1987. Ponderosa pine managed-yield simulator: PPSIM users guide. Gen. Tech. Rep. PNW-GTR-203, USDA For. Serv. PNW Res. Stn. Portland, OR. 36 p.

Drew, T.J., and J.W. Flewelling. 1979. Stand density management: An alternative approach and its application to Douglas-fir plantations. For. Sci. 25:518-532.

Dunning, D. 1942. A site classification for the mixed-conifer selection forests of the Sierra Nevada. Res. Note 28. USDA For. Serv. California For. and Range Exp. Stn. Berkeley, CA. 21 p.

Echols, R.M. 1972. Patterns of wood density distribution and growth rate in ponderosa pine. Pp. H1-H15 *In:* Symposium on the effect of growth acceleration on the properties of wood. USDA For. Serv. Wood Products Laboratory. Madison WI.

Edminster, C.B. 1988. Stand density and stocking in even-aged ponderosa pine stands. P. 253-259 *In*: Baumgartner, D.M., and J.E. Lotan (Editors). Ponderosa pine the species and its management. Washington State University Cooperative Extension, Pullman WA.

Egan, J.M., W.R. Jacobi, J.F. Negron, S.L. Smith, and D.R. Cluck. 2010. Forest thinning and subsequent bark beetle-caused mortality in northeastern California. For. Ecol. Manage. 260:1832-1842.

Espinosa-Bancalari, M., and D. Perry. 1987. Distribution and increment of biomass in adjacent young Douglas-fir stands with different early growth rates. Can. J. For. Res. 17:722-730.

Ferguson, D.E., J.C. Byrne, W.R. Wykoff, B. Kummet, and T. Hensold. 2011. Response of ponderosa pine stands to precommercial thinning on Nez Perce and Spokane Tribal Forests in the inland northwest, USA. Res. Pap. RMRS-RP-88. USDA For. Serv. Rocky Mtn. Res. St. Fort Collins CO. 33 p.

Fettig, C.J., J.D. McMillin, J.A. Anhold, S.M. Hamud, R.R. Borys, C.P. Dabney, and S.J. Seybold. 2006. The effects of mechanical fuel reduction treatments on the activity of bark beetles (*Coleoptera*: *Scolytidae*) infesting ponderosa pine. For. Ecol. Manage. 230:55-68.

Fettig, C.J., K.D. Klepzig, R.F. Billings, A.S. Munson, T.E. Nebeker, J.F. Negrón, and J.T. Nowak. 2007. The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in coniferous forests of the western and southern United States. For. Ecol. Manage. 238:24-53.

Filip, G.M. J.J. Bronson, K.L. Chadwick, J.B. Filip, S.J. Frankel, D.J. Goheen, E.M. Goheen, S.R. Mori, and A.L. Saavedra. 2015. Precommercial thinning in mixed-species conifer plantations affected by *Armillaria* and *Heterobasidion* root diseases in west-central Oregon and Washington: 30-year results. For. Sci. 61:914-925.

Filip, G.M., K.L. Chadwick, S.A. Fitzgerald, and T.A. Max. 2009. Thinning ponderosa pine affected by *Armillaria* root disease: 40 years of growth and mortality in central Oregon. West. J. Appl. For. 24:99-94.

Filip, G.M., and D.J. Goheen. 1995. Precommercial thinning in *Pseudotsuga*, *Tsuga* and *Abies* stands affected by armillaria root disease: 10-year results. Can. J. For Res. 25:817-823.

Filipescu, C.N., E.C. Lowell, R. Koppenaal, and A.K. Mitchell. 2014. Modeling regional and climatic variation of wood density and ring width in intensively managed Douglas-fir. Can. J. For. Res. 44:220-229.

Flewelling, J.W. and T.J. Drew. 1985. A stand density management diagram for lodgepole pine. *In:* Baumgartner, D.M., R.G. Krebill, J.T. Arnott, and G.F. Weetman (Editors). Lodgepole pine: the species and its management. Washington State University Cooperative Extension.

Giusti, G.A. 1990. Black bear feeding on second growth redwoods: A critical assessment. Pp. 214–217 *In*: Davis, L.R., and R.E. Marsh (Editors). Proceedings of the 14th vertebrate pest conference.. University of California—Davis, CA.

Glebocki, R. 2015. Fuel loading and moisture dynamics in thinned coast redwood – Douglas-fir forests in Headwaters Forest Reserve, California. M.Sc. thesis, Humboldt State University, Arcata, California. 95 p.

Goheen, D.J., and E.M. Hansen. 1993. Effects of pathogens and bark beetles on forests. Pp. 175-196 *In:* T.D. Schowalter, and G.M. Filip (Editors). Beetle-pathogen interactions in conifer forests. Academic Press, London.

Graham, R.T., A.E. Harvey, T.B. Jain, and J.R. Tonn. 1999. The effects of thinning and similar stand treatments on fire behavior in western forests. Gen. Tech. Rep. PNW-GTR-463. USDA For. Serv. PNW Res. Stn. Portland, OR. 27 p.

Harrington, C.A. and D.L. Reukema. 1983. Initial shock and long-term stand development following thinning in a Douglas-fir plantation. For. Sci. 29:33-46.

Harrington, T.C., C. Reinhart, D.A. Thornburgh, and F.W. Cobb Jr. 1983. Association of black-stain root disease with precommercial thinning of Douglas-fir. For. Sci. 29:12-14.

Harrington, T.C., and J.C. Tappeiner. 2009. Long-term effects of tanoak competition on Douglas-fir stand development. Can. J. For. Res. 39(4):765-776.

Helms, J.A. 1998. The dictionary of forestry. Society of American Foresters. Bethesda. MD. 210 p.

Hessburg, P.F., D.J. Goheen, and H. Koester. 2001. Association of black stain root disease with roads, skid trails and precommercial thinning in southwestern Oregon. West. J. Appl. For. 16:127-135.

Hosack, D.A., and K.O. Fulgham. 1998. Black bear damage to regenerating conifers in Northwestern California. J. Wildl. Res. 1(1):32-37.

Jain, T.B., M.A. Battaglia, H-S. Han, R.T. Graham, and C.R. Keyes. 2012. A comprehensive guide to fuel management practices for dry mixed conifer forests in the northwestern United States. USDA Forest Service, General Technical Report RMRS-GTR-292.

Jameson, M.J., and T.A. Robards. 2007. Coast redwood regeneration survival and growth in Mendocino County, California. West. J. Appl. For. 22(3):171–175.

Jozsa, L.A., and H. Brix. 1989. The effects of fertilization and thinning on wood quality of a 24–year-old Douglas-fir stand. Can. J. For. Res. 19:1137-1145.

Kegley, S.J., R.L. Livingston, and K.E. Gibson. 1997. Pine engraver, *Ips pini* (Say) in the western United States. Forest Insect and Disease Leaflet 122. USDA, For. Serv.

Keyes, C.R., and K.L. O'Hara. 2002. Quantifying stand targets for silvicultural prevention of crown fires. West. J. Appl. For. 17(2):101–109.

Keyes, C.R., P.J. Matzka, K.C. Wright, R. Glebocki, and H.S. Han. 2008. Early precommercial thinning of redwood sprout clumps: Evaluation of four techniques. Int. J. For. Eng. 19(2):28–36.

Kirk, C., and J-P. Berrill. 2016. Second-log branching in multiaged redwood and Douglas-fir: influence of stand, site, and silviculture. Forests 7(147):1-15.

Krieger, R.M.; Wall, B.E.; Kidd, C.W.; Berrill, J-P. 2020. Chronosequence of fuel loading and fuel depth following forest rehabilitation frill treatment of tanoak to release Douglas-fir: a case study from northern California. Forests 2020, 11(6), 691; https://doi.org/10.3390/f11060691

Larsson, S., R. Oren, R.H. Waring, and J.W. Barrett. 1983. Attacks of mountain pine beetle as related to tree vigor of ponderosa pine. For. Sci. 29:395-402.

Leonard, L.P., Berrill, J-P., and C.M. Dagley. 2017. Ecosystem responses to variable-density thinning for forest restoration in Mill Creek. P. 287-290 *In:* Standiford, R.B., and Y. Valachovic (Tech. Coords.). Proceedings of coast redwood science symposium—2016: Past successes and future direction. Gen. Tech. Rep. PSW-GTR-258. USDA For. Serv. PSW Res. Stn. Albany, CA. 446 p.

Lindquist, J.L. 2004. Precommercial stocking control of coast redwood: A seventeen-year status report (1981–1998). Calif. For. Rep. No. 2, Sacramento, CA. 24 p.

Lindquist, J. 2007. Precommercial stocking control of coast redwood at Caspar Creek, Jackson Demonstration State Forest. Pp. 295–304 *In:* Standiford, R.B., G.A. Giusti, Y. Valachovic, W.J. Zielinski, and M.J. Furniss (Editors). Proceedings of the redwood region forest. Science symposium: What does the future hold?. Gen. Tech. Rep. PSW-GTR-194. USDA For. Serv. PSW Res. Stn. Albany, CA.

Long, J.N. 1985. A practical approach to density management. For. Chron. 61(1):23–27.

Long, J.N., and T.W. Daniel. 1990. Assessment of growing stock in uneven-aged stands. West. J. of Appl. For. 5:93-96.

Long, J.N., and J.D. Shaw. 2005. A density management diagram for even-aged ponderosa pine stands. West. J. Appl. For. 20:205-215.

Long, J.N., and J.D. Shaw. 2012. A density management diagram for even-aged Sierra Nevada mixed-conifer stands. West. J. of Appl. For. 27:187-195.

Maguire, D.A., J.A. Kershaw, and D.W. Hann. 1991. Predicting the effects of silvicultural regime on branch size and crown wood core in Douglas-fir. For. Sci. 37:1409–1428.

Markstrom, D.C., H.E. Troxell, and C.E. Boldt. 1983. Wood properties of immature ponderosa pine after thinning. For. Prod. Journ. 33:333-36.

McCarter, J.B., and J.N. Long. 1986. A lodgepole pine density management diagram. West. J. Appl. For. 1:6-11.

McConnell, B.R., and J.G. Smith. 1970. Response of understory vegetation to ponderosa pine thinning in eastern Washington. J. Range Manage. 23:208-212.

Monleon, V.J., M. Newton, C. Hooper, and J.C. Tappeiner II. 1999. Ten-year growth response of young Douglas-fir to variable density varnishleaf ceanothus and herb competition. West. J. of Appl. For. 14:208-213.

Neal, R.L. Jr. 1967. Sprouting of old-growth redwood stumps—First year after logging. Res. Note PSW-137. USDA For. Serv. PSW For. and Range Exp. Stn. Berkeley, CA. 8 p.

Odhiambo, B., M. Meincken, and T. Seifert. 2014. The protective role of bark against fire damage: a comparative study on selected introduced and indigenous tree species in the Western Cape, South Africa. Trees 28:555-565.

O'Hara, K.L. 2012. Coast redwood responses to pruning. Pp. 529-538 *In:* Standiford, R.B., T.J. Weller, D.D. Piirto, and J.D. Stuart (Tech. Coords.). Proc. of coast redwood forests in a changing California: a symposium for scientists and managers. Gen. Tech. Rep. PSW-GTR-238. USDA For. Serv. PSW Res. Stn. Albany, CA. 675 p.

O'Hara K.L., and J-P. Berrill. 2009. Epicormic sprout development in pruned coast redwood: pruning severity, genotype, and sprouting characteristics. Annals For. Sci. 66(409):1-9.

O'Hara, K.L., and J-P. Berrill. 2010. Dynamics of coast redwood sprout clump development in variable light environments. J. For. Res. 15(2):131–139.

O'Hara, K.L., P.T. Stancioiu, and M.A. Spencer. 2007. Understory stump sprout development under variable canopy density and leaf area in coast redwood. For. Ecol. Manage. 244(1–3):76–85.

O'Hara, K.L., D.A. Larvik, N.I. Valappil. 1995. Pruning costs for four northern rocky mountain species with three equipment combinations. West. J. Appl. For. 10(2):59–65.

O'Hara, K.L., R.A. York, and R.C. Heald. 2008. Effect of pruning severity and timing of treatment on epicormic sprout development in giant sequoia. Forestry 81(1):103–110.

O'Hara, K.L., L.A. Grand, and A.A. Whitcomb. 2010. Pruning reduces blister rust in sugar pine with minimal effects on tree growth. California Ag. 64(1):31-36.

O'Hara, K.L., J.C.B. Nesmith, L. Leonard, and D.J. Porter. 2010. Restoration of old forest features in coast redwood forests using early stage variable-density thinning. Restoration Ecol. 18:125–135.

O'Hara, K.L., L.P. Leonard, and C.R. Keyes. 2012. Variable-density thinning and a marking paradox: Comparing prescription protocols to attain stand variability in coast redwood. West. J. Appl. For. 27(3):143–149.

O'Hara, K.L., L. Narayan, and K.G. Cahill. 2015. Twelve-year response of coast redwood to precommercial thinning treatments. For. Sci. 61(4):780-789.

Oliver, C.D., and B.C. Larson. 1996. Forest stand dynamics. Update edition. John Wiley and Sons, New York, NY.

Oliver, W.W., and R.F. Powers. 1971. Early height growth of ponderosa pine forecasts dominance in plantations. Res. Note PSW-250. USDA For. Serv. PSW Res. Stn. Berkeley CA. 5 p.

Oliver, W.W. 1979a. Fifteen-year growth patterns after thinning a ponderosa pine-Jeffrey pine plantation in northeastern California. Res. Pap. RP-PSW-141. USDA For. Serv. PSW Res. Stn. Berkeley, CA. 10 p.

Oliver, W.W. 1979b. Growth of planted ponderosa pine thinned to different stocking levels in Northern California. Res. Pap. RP-PSW-147. USDA For. Serv. PSW For. and Range Exp. Stn. Berkeley CA. 11 p.

Oliver, W.W. 1984. Brush reduces growth of thinned ponderosa pine in northern California. Res. Pap. PSW-172. USDA For. Serv. PSW For. and Range Exp. St. Berkeley, CA. 7 p.

Oliver, W.W. 1995. Is self-thinning in ponderosa pine ruled by *Dendroctonus* bark beetles? P 213-218 *In:* Proceedings of the 1995 National Silviculture Workshop. Gen. Tech. Rep. GTR-RM-267. USDA For. Serv. Rocky Mtn. Res. Stn. Fort Collins CO.

Oliver, W.W. 1997. Twenty-five-year growth and mortality of planted ponderosa pine repeatedly thinned to different stand densities in northern California. West. J. Appl. For. 12:122-130.

Oliver, W.W., J.L. Lindquist, and R.O. Strothmann. 1994. Young growth redwood stands respond well to various thinning intensities. West. J. Appl. For. 9(4):106 –112.

Oliver, W.W., and R.F. Powers. 1978. Growth models for ponderosa pine: I Yield of unthinned plantations in northern California. Research Paper PSW-133. USDA Forest Service Pacific Southwest Forest and Range Experiment Station. 21 p.

Oliver, W.W. and J. Trask. 1983. Responses of eastside pine to precommercial thinning. Pp 107-113 *In*: Robson, T.F., and R.B. Standiford (Editors). Management of the eastside pine type in northeastern California; Proceedings of a symposium. Susanville California, June 15-17, 1982. Northern California Society of American Foresters. 139 p.

Perry, D.W., L.W. Breshears, G.E. Gradillas, and J-P. Berrill. 2016. Thinning intensity and ease-of-access increase probability of bear damage in a young coast redwood forest. J. of Biodiv. Manage. and For. 5(3):1-7.

Plummer, J.F., C.R. Keyes, and J.M. Varner. 2012. Early-stage thinning for the restoration of young redwood—Douglas-fir forests in northern coastal California, USA. ISRN Ecol. doi:10.5402/2012/725827.

Pollet, J., and P.N. Omi. 2002. Effect of thinning and prescribed burning on crown fire severity in ponderosa pine forests. Int. J. of Wildl. Fire 11:1-10.

Powers, E.M., J.D. Marshall, J. Zhang, and L. Wei. 2013. Post-fire management regimes affect carbon sequestration and storage in a Sierra Nevada mixed-conifer forest. For. Ecol. Manage. 291:268-277.

Powers, R.F. and W.W. Oliver. 1970. Snow breakage in a pole-sized ponderosa pine plantation… more damage at high stand densities. Res. Note PSW-218. USDA For. Serv. PSW For. and Range Exp. Stn. Berkeley CA. 3 p.

Powers, R.F., and P.E. Reynolds. 1999. Ten-year responses of ponderosa pine plantations to repeated vegetation and nutrient control along an environmental gradient. Can. J. For. Res. 29:1027-1038.

Reineke, L.H. 1933. Perfecting a stand density index for even-aged forests. J. of Ag. Res. 46:627-638.

Reukema, D.L. 1975. Guidelines for precommercial thinning of Douglas-fir. Gen. Tech. Rep. PNW-30, USDA For. Serv. PNW For. and Range Exp. Stn. Portland OR. 10 p.

Reukema, D.L., and D. Bruce. 1977. Effects of thinning on yield of Douglas-fir: concepts and some estimates obtained by simulation. Gen. Tech. Rep. PNW-58. USDA For. Serv. PNW For. and Range Exp. Stn. Portland OR. 36 p.

Ritchie, M.W. 1999. A compendium of forest growth and yield simulators for the Pacific coast states. Gen. Tech. Rep. PSW-GTR-174. USDA For. Serv. PSW Res. Stn. 59 p.

Ritchie, M.W. 2020. Relating stocking and density for natural regeneration of conifers in northern California. For. Sci. fxaa005. doi:10.1093/forsci/fxaa005.

Ritchie, M.W., and J. Zhang 2018. OP-Yield Version 1.00 user's guide. Gen. Tech. Rep. PSW-GTR-259. USDA For. Serv. PSW Res. St. Albany, CA. 26 p.

Robertson, A.S., and J.E. Dewey. 1983. Determination of western pine shoot borer incidence, impact and stand hazard rating characteristics in selected Region one National Forests. Report No. 83-10. USDA For. Serv., North. Region, State and Private Forestry.

Ryan, K.C., and E.D. Reinhardt. 1988. Predicting postfire mortality of seven western conifers. Can. J. For. Res. 18:1291-1297.

Sartwell, C. 1970. *Ips pini* attack density in ponderosa pine thinning slash as related to felling date in eastern Oregon. Res. Note PNW-131, USDA For. Serv. PNW For. and Range Exp. Stn. Portland OR. 8 p.

Sartwell, C. 1971. Thinning ponderosa pine to prevent outbreaks of mountain pine beetle. P. 41-52 *In:* Baumgartner, D.M. (Editor). Precommercial thinning of coastal and intermountain forests in the Pacific Northwest. Pullman WA. Washington State University.

Sartwell, C., and R.E. Stevens. 1975. Mountain pine beetle in ponderosa pine, prospects for silvicultural control in second-growth stands. J. For. 73:136-140.

Staebler, G.R. 1956. Evidence of shock following thinning of young Douglas-fir. J. For. 54:339.

Stein, W.I. 1978. Reforestation evaluation. Pp. 205-221 *In:* Cleary, B.D., R.D. Greaves, and R.K. Hermann (Editors). Regenerating Oregon's forests, a guide for the regeneration forester. Oregon State University Extension Service, Corvallis Oregon.

Stein, W.I. 1992. Regeneration surveys and evaluation. Pp. 346-382 *In:* Hobbs, S.D., S.D. Tesch, P.W. Owston, R.E. Stewart, J.C. Tappeiner, and G.E. Wells (Editors). Reforestation practices in southwestern Oregon and northern California. Oregon State University Forestry Research Laboratory, Corvallis Oregon.

Stephens, S.L. 1998. Evaluation of the effects of silvicultural and fuels treatments on potential fire behavior in Sierra Nevada mixed-conifer forests. For. Ecol. Manage. 105(1-3):21-35.

Talbert, C., and D. Marshall. 2005. Plantation productivity in the Douglas-fir region under intensive silvicultural practices: results from research and operations. J. For. 103:65-70.

Tappeiner, J.C. II, D.A. Maguire, and T.B. Harrington. 2007. Silviculture and ecology of western U.S. forests. Oregon State University Press, Corvallis OR.

Teraoka, J.R., and C.R. Keyes. 2011. Low thinning as a forest restoration tool at Redwood National Park. West. J. Appl. For. 26(2):91–93.

Thomas, S.C., C.B. Halpern, D.A. Falk, D.A. Liguori, and K.A. Austin. 1999. Plant diversity in managed forests: understory responses to thinning and fertilization. Ecol. App. 9:864-879.

Thornburgh, D.A., R.F. Noss, D.P. Angelides, C.M. Olson, F. Euphrat, and H.H. Welsh Jr. 2000. Managing redwoods. Pp. 229–262 *In:* Noss, R.F. (Editor). The redwood forest: History, ecology, and conservation of the coast redwoods. Island Press, Washington, DC.

Tu, M., C. Hurd, and J.M. Randall. 2001. Weed control methods handbook: tools & techniques for use in natural areas. The Nature Conservancy. Last accessed May 10 2020: https://www.invasive.org/gist/handbook.html

USDA Forest Service. 2009. A user's guide to thinning with mastication equipment. USDA Forest Service Pacific Northwest Region, Okanogan-Wenatchee National Forest. 7p.

Valachovic, Y.S., C.A. Lee, H. Scanlon, J.M. Varner, R. Glebocki, B.D. Graham, and D.M. Rizzo. 2011. Sudden oak death-caused changes to surface fuel loading and potential fire behavior in Douglas-fir-tanoak forests. For. Ecol. Manage. 261(11):1973-1986.

Webb, L.A, J.L. Lindquist, E. Wahl, and A. Hubbs. 2012. Whiskey springs long-term coast redwood density management; final growth, sprout, and yield results. Pp. 571-581 *In:* Standiford, R.B., T.J. Weller, D.D. Piirto, and J.D. Stuart. (Tech. Coords.). Proc. of Coast redwood forests in a changing California: a symposium for scientists and managers. Gen. Tech. Rep. PSW-GTR-238. USDA For. Serv. PSW Res. Stn. Albany, CA. 675 p.

Webb, L., J-P. Berrill, and J. Lindquist. 2017. Long term results of early density management of a third growth redwood stand. Pp. 267-278 *In:* Standiford, R.B., and Y. Valachovic (Tech. Coords.). Proceedings of coast redwood science symposium—2016: Past successes and future direction. Gen. Tech. Rep. PSW-GTR-258. USDA For. Serv. PSW Res. Stn. Albany, CA. 446 p.

Webster, J. 1997. Pre-commercial thinning of plantations, why, when and how? An industrial perspective for interior California. Pp. 83-87 *In:* 18th Annual forest vegetation management conference. Univ. of Cal. Coop. Ext. For. Prog.

Webster, J., and E. Fredrickson. 2005. Lessons Learned on 50,000 acres of Plantation in Northern California. Pp 267-281 *In:* Ritchie, M.W., D.A. Maguire, and A. Youngblood (Tech. Coords.) Proceedings of the symposium on ponderosa pine: issues, trends, and management, 2004 October 18-21, Klamath Falls, OR. PSW-GTR-198. USDA For Serv. PSW Res. Stn. Albany, CA. 281 p.

Weiskittel, A.R., L.S. Kenefic, R.S. Seymour, and L.M. Phillips. 2009. Long-term effects of precommercial thinning on the stem dimensions, form and branch characteristics of red spruce and balsam fir crop trees in Maine, USA. Silva Fennica 43:397-409.

Weiskittel, A.R., D.A. Maguire, and R.A. Monserud. 2007. Response of branch growth and mortality to silvicultural treatments in coastal Douglas-fir plantations: Implications for predicting tree growth. For. Ecol. Manag. 251:182–194.

White, D.E., and M. Newton. 1988. Competitive interactions of whiteleaf manzanita, herbs, Douglas-fir, and ponderosa pine in southwest Oregon. Can. J. For. Res. 19:232-238.

Wiant, H.V. Jr., and R.F. Powers. 1967. Sprouting of old-growth redwood. P. 88–90 in Proc. Soc. Am. For., 1966. Society of American Foresters, Washington, DC. 232 p.

Windell, K. 1998. Understory biomass reduction: initial report to the national fuels specialists. USDA For. Serv. Tech. and Dev. Prog. Missoula Montana. 22p.

Woodruff, W., D. Greenberg, and P. Cannon. 2019. Results of a thinning study in a black stain (*Leptographium wageneri*)-infested Jeffrey/ponderosa pine forest in northern California. For. Path. 49:e12551.

Zhang, J., W.W. Oliver, and M.D. Busse. 2006. Growth and development of ponderosa pine on sites of contrasting productivities: relative importance of stand density and shrub competition effects. Can. J. For. Res. 36:2426-2438.

Zhang, J., M.W. Ritchie, and D.A. Maguire. 2013. Thinning ponderosa pine (*Pinus ponderosa*) stands reduces mortality while maintaining stand productivity. Can. J. For. Res. 43:311-320.

Zald, H.S., A.N. Gray, M. North, and R.A. Kern. 2008. Initial tree regeneration responses to fire and thinning treatments in a Sierra Nevada mixed-conifer forest, USA. For. Ecol. Manag. 256:168-179.

Zeibig-Kichas, N.E., Ardis, C.W., Berrill, J-P., and J.P. King. 2016. Bark thickness equations for mixed-conifer forest type in Klamath and Sierra Nevada mountains of California. Int. J. For. Res., Vol. 2016, ID: 1864039, 1-10.

Chapter 11: Damage

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General Guidelines

This chapter addresses biotic and abiotic causes of damage to conifer seedlings, saplings and young trees. It starts with general guidelines for assessing, preventing and mitigating damage, followed by more detailed information and illustrations of the most common causes of damage. Damaging agents are grouped and discussed as follows: insects, diseases, vertebrates, and abiotic. Understanding and diagnosing the broad topic of damage draws from multiple disciplines and specialties. A basic understanding of damaging agents is assumed. Competing vegetation can also be thought of as a cause of damage. However, it is discussed extensively elsewhere in the manual, and thus is not specifically addressed here.

Damage to young conifers comes in many forms. Pest organisms – insects, pathogens, and vertebrates - often are involved, but adverse environmental conditions can lead to damage without the involvement of any pests. Knowledge of what damage has previously occurred in an area or under similar circumstances can allow land managers to anticipate what might occur, recognize the source of the damage, and act accordingly. Ultimately, it is difficult to anticipate and recognize *all* the variables that might lead to damage. When damage does occur, land managers mainly want to know "will this damage continue and if it does, is there anything that can be done to prevent it?" To answer these questions, an accurate diagnosis of the situation is essential. Regardless of your level of skill or comfort at making a diagnosis, the process of assessing damage is invaluable because it will sharpen your skills of observation and enable you to better understand the situation. You may then either feel confident to make a diagnosis or decide to consult an expert.

Assessing Damage

A simple but useful model to keep in mind when evaluating damage is the Pest Triangle (fig. 11.1). Pests are strongly influenced by host and environmental conditions. All three points of the triangle interact to produce the resultant damage and all three points must be considered when formulating a diagnosis, and, ultimately, a prognosis of what is to come.

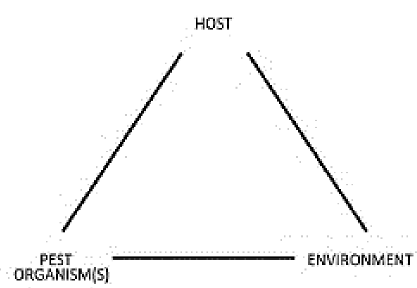


Figure 11.1 Pest Triangle

Common mistakes made during diagnosis include an imbalanced interpretation of how points of the triangle are interacting, and a misidentification, or lack of recognition, of one or more of the factors that have contributed to damage. If a pest organism is present or easily identifiable, it is not uncommon for most of the blame to be placed on it, with the belief that eliminating the pest will bring an end to damage. If a key pest organism is misdiagnosed or unrecognized, time and resources may be wasted trying to manage the wrong pest or condition.

It is important to thoroughly investigate both the damage and the context in which it occurs. Look for clues at multiple levels – on the damaged tree(s), within the stand, and across the region. Explore the patterns and extent of damage, associated environmental conditions, and other clues that may arise during an on-site assessment. Obtain as much background information as possible on site conditions such as soil properties, weather events, source of growing stock, history of damaging agents onsite, and management actions – anything that could have had bearing on the damage. Context is invaluable since many types of damage are associated with predictable conditions.

Inspect damage on all or a representative number of trees, and inspect entire trees to the extent possible. The source of damage may not be obvious, especially if the damage is old or multiple organisms are present. It is common for insects and disease organisms to invade wounded or stressed tissue and, in doing so, mask more relevant signs and symptoms of damage. The sooner an inspection is conducted after damage has occurred, the better. Roots should not be overlooked since above-ground symptoms can be caused by below-ground damage or conditions.

Trees are only able to respond to damage in a limited number of ways. Symptoms are the generic expression or consequence of damage. As such, they may allow an educated guess as to what is occurring, but they typically do not provide a definitive answer. For example, brown needles at the ends of branches are a symptom that can be caused by insects, diseases, vertebrates, or abiotic factors. Additional clues collected at the tree, stand, and regional levels may help to narrow the choices, such as size and species of trees impacted, type of damage (e.g. length of brown needles), and distribution of damage within tree crowns and across the stand and region. Validate a diagnosis by looking for signs of a pest organism or evidence of a specific type of injury. Signs of biotic damage include evidence that a pest organism is or has been present, such as insect life stages or remains (e.g. larvae, pupal cases, dead adults), tunnels and galleries, chewed tissue, frass, fungal staining, mycelium, zone lines, fruiting bodies, or parasitic plants (e.g. mistletoe). Signs of abiotic damage include physical wounds and tissue death that often occur in distinct patterns and are not associated with living organisms.

Damage that occurs to a cohort of trees over a relatively short or otherwise distinct period of time is usually caused by a specific set of conditions. It is important to mentally reference the pest triangle and look for patterns in the symptoms of damage, species and size of trees impacted, associated environmental conditions, and signs of pest organisms. If a pest organism is a principal contributor to damage, it should be possible to identify signs or symptoms of that organism on all or most of the trees inspected. Finding such evidence, however, may be limited by how thoroughly the tree is inspected. If evidence for a specific pest organism is inconsistent, consider that a different organism may be contributing to the damage or that pest organisms are primarily acting in a secondary role.

Also, consider that certain pests are frequently found together in what are referred to as pest complexes. Bark beetles and root diseases are a good example of this. While bark beetles can kill trees on their own, quite often the success of their attack is facilitated by a preexisting condition that weakens the tree, such as root disease, injury, or drought stress. An awareness of pest complexes and investigating their presence is an important aspect of diagnosis.

In most cases, signs and symptoms will lead to a diagnosis in the field. Occasionally, samples of damaged tissue may need to be taken to a lab for dissection, incubation, or some other diagnostic procedure (see Additional Resources section of this chapter). If the lab diagnostician has not seen the damage in the field, it is important that they be provided with as much relevant information as is possible (e.g., geographical location, elevation, aspect, tree species, tree size). A prognosis can only be made once damage has been accurately diagnosed.

Damage caused by abiotic factors is often limited in duration, for example a late frost, hail, or herbicide treatment. It also tends to be more uniformly and widely distributed, both on individual trees, across tree species, and across the landscape. In some cases, the damage may be vague and non-specific, with no or inconsistent signs of pest organisms. Abiotic factors typically cause no further damage, although it may take time for damage to be fully expressed. Secondary insects and disease organisms may initially be absent, but often invade damaged tissue over time. Usually their contribution to damage is minimal.

Pest organisms vary widely in the damage they cause and their ability to persist on site. A prognosis depends on the biology of the individual organism(s) as well as an accounting of factors that influence future pest abundance and damage. The probability of future damage coupled with management options makes a prognosis complete. Are pest organisms still present and at what level? Are they likely to increase or decrease? What factors, including treatment options, will influence their abundance and ability to cause additional damage? An initial evaluation may be sufficient to answer these questions, or it may be desirable to conduct follow-up surveys.

Preventing Damage – Best Management Practices

A certain amount of pest damage is preventable to the extent that it is related to management choices. Prevention practices that are specific to one or a small group of pests are discussed in the individual pest sections. Generic considerations are discussed here. Prevention practices should be thought of as best management practices since the intent is to produce the best possible outcome.

Because tree genetics are closely aligned with environmental conditions, it is essential that locally-adapted seed or seedlings are used for reforestation (see discussion of Seed Zones in this manual). There are many examples of "off-site" plantings suffering pest damage. While such trees may initially grow well, they are poorly suited for the site and often succumb to pest damage before reaching merchantable size.

Reducing competition between trees and associated vegetation improves tree growth and is an important factor in reducing pest damage on drier sites. Treatments include thinning (stocking control) of plantation trees and various methods of controlling competing vegetation. There are some precautions to take when thinning since it can lead to pest damage under certain conditions. These are discussed in the individual pest sections.

On forestlands that naturally support a mixture of tree species and ages, one of the challenges of reforestation efforts is to promote and maintain a diversity of these two characteristics. Reforestation following wildfire is a challenge because only a limited number of tree species may be able to survive when planted into a post-fire landscape. With large wildfires, there is the additional challenge of finding sufficient amounts of seed or seedlings adapted to the local area. Pest-caused damage often occurs in large plantations with little diversity in tree age and species. Planting stock that is not well matched with local conditions may further contribute to damage.

Mitigating Damage – Options for Response

Mitigation or management options usually depend on the specific pest(s) and circumstances involved. In the following pest sections, the most commonly encountered plantation pests are discussed, including information on identification, life history, and management. Direct control of a pest is one of many options that might be considered under the more holistic strategy of integrated pest management (IPM). Understanding the ecological relationships between host / pest / environment (fig. 11.1) is central to the concept of IPM. Thus, a variety of options are weighed and integrated into an ecologically sound response. Modern definitions of IPM also typically incorporate the concepts of economic efficiency and social acceptance. When thinking about mitigation, it is important to have a realistic expectation of what is possible from both an ecological and cost/benefit standpoint. Some pest damage may be difficult to avoid or too costly to mitigate. Doing nothing is sometimes the best or only alternative.

Insect Pests

Much of the insect damage that occurs to young trees is insignificant, not encountered, or is simply different on older trees. Thus, plantation insect pests are, for the most part, a distinct subset of the larger group of insects that damage trees.

Insects that Attack Roots and the Lower Stem

Recognition and Significance: The first year or two of a tree's life is a critical time for root damage from insects. The insects involved are rarely primary pests of conifers, but have largely been studied as agricultural or ornamental pests. Often, they cause damage when conifer seedlings grow along side of or replace vegetation that the insects were feeding upon. Sites where herbaceous vegetation is well established are prone to damage. Removing this and other competing vegetation by chemical or cultural means will lead to the insect populations dying out, but the effect is not immediate. See Forest Nursery Pests, USDA Handbook # 680, for coverage of the most common of these pests (https://www.fs.fed.us/sites/default/files/legacy_files/Forest%20Nursery%20Pests-web.pdf)

These insects come in many forms and typically do not need to be identified precisely. Common names include white grubs (larvae of beetles in the family Scarabidae), cutworms (caterpillars of moths in the family Noctuidae), root weevils (beetle larvae in the genus *Otiorhyncus*), and sod webworms (caterpillars of moths in the family Pyralidae). Immature stages of the insects (larvae and caterpillars) live in the soil and feed on roots, the lower stem, or sometimes foliage. An initial symptom of root or lower stem feeding is a change in the foliage color of seedlings. Heavily damaged seedlings continue to fade and die, while less damaged seedlings may survive with reduced growth. Some adult weevil species will girdle seedlings, while their larvae feed on other plants.

Any time the entire top of the tree appears off color or shows reduced growth, suspect an issue with the roots. These symptoms can be the result of poor planting (e.g. J-roots), vertebrate pests, diseases, herbicides, or insects. Inspect the roots and lower stem for insect feeding damage, including missing bark, consumption of finer roots, or young shoots clipped at the soil line. Look for larvae, caterpillars, or evidence of insects, such as frass and webbing, in the soil near roots. Cutworms and weevils may also feed on needles. Be aware that vertebrates can cut or tear foliage and stems with their teeth, causing damage in the absence of insects or disease. Intact, apparently healthy roots combined with foliage discoloration may indicate herbicide or abiotic damage. Other signs and symptoms may indicate disease (see Disease Section below).

Management Options: While direct control of insects may be prescribed for seedlings in nurseries, it is rarely recommended for seedlings and young trees in forest plantations because damage is typically limited in scope and duration. Damage is rare when plantations are established soon after the harvest of over-story trees. Damage is possible if herbaceous and other vegetation becomes well established, such as when a site remains free of trees for an extended period. On such sites, control competing vegetation and consider a fallow period before planting trees to reduce the possibility of insects surviving in the soil and feeding on seedlings.

Insects that Attack the Main Stem

These insects feed in the cambial region, girdling the stem and killing the entire tree or a portion of it. Bark beetles and some weevils can do this to advanced regeneration under drought stress, particularly to species of pine. Other factors that stress young trees potentially predispose them to attack by this group of insects.

Pine Reproduction Weevil

Recognition and Significance: The pine reproduction weevil, *Cylindrocopturus eatoni,* kills young pines, in whole or in part (fig. 11.2). Ponderosa pine is the primary host, but Jeffrey, sugar, foothill, and other pines are attacked. Trees taller than 5 feet in height are rarely killed.

Figure 11.2 Ponderosa pines killed by the pine reproduction weevil.

The weevil life cycle is one year. Adults are tiny, about 2.5 mm long (fig. 11.3) and emerge from dead trees in the spring (May-June), creating small exit holes in the bark.

Figure 11.3 Adult pine reproduction weevil.

Adults do minor feeding on the host, creating diagnostic puncture wounds on needles (fig. 11.4). Females lay eggs one at a time on the stems of live trees in early summer. Larvae tunnel in the cambial region, girdling the stem, and eventually enter the wood or pith to overwinter.

Figure 11.4 Ponderosa pine needles with puncture wounds from pine reproduction weevil.

A blue fungal stain discolors the wood (fig. 11.5). Pupation occurs in the spring prior to adult emergence. Foliage of killed trees begins to change color (fade) in the fall or the following spring. Diagnosis is readily made based on these signs and symptoms.

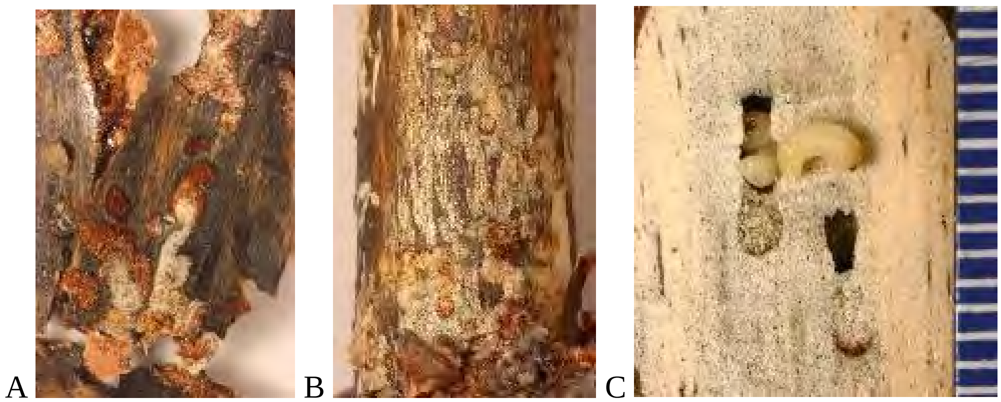


Figure 11.5 Evidence of pine reproduction weevil in a killed ponderosa pine. (A) Inner bark surface and (B) surface of wood show mines and staining. (C) Larvae tunnel in to the wood prior to pupation; associated stained wood.

A related insect, the Douglas-fir twig weevil, *Cylindrocopturus funissi,* is similar in appearance, life cycle and the damage it causes, although mortality is usually restricted to twigs and branches. Management is the same for both insects.

Management Options: Direct control of weevil populations is done by destroying infested trees or applying contact pesticides to kill the adults, but does not produce a lasting solution. Weevils reinvade plantations where trees are under stress, allowing populations and damage to rebuild. Controlling vegetation that competes with trees for limited water is the recommended treatment, as it enables trees to better resist attacks by weevils and other insects. On sites that are marginal for conifer growth and survival, the costs of keeping planted pines alive may outweigh the benefits.

Bark Beetles Attacking Young Pines

Recognition and Significance: Several bark beetle species can kill young conifers during drought. These beetles also attack older trees, but are not primary killers of mature trees. Susceptible tree height and diameter are greater than for trees damaged by *Cylindrocopturus* weevils. Mortality events are typically short-term and often precipitated by thinning stressed host trees at an inappropriate time. In pine plantations, species of *Ips*, especially California five-spined Ips, *I. paraconfusus,* can kill sapling and pole-size trees. The red turpentine beetle (RTB), *Dendroctonus valens*, can kill pole-size trees. Bark beetle attacks are distinguished from those of the pine reproduction weevil by the larger size of tree attacked and the presence of boring dust or pitch tubes on the main stem. Key factors in bark beetle-caused mortality are drought and a productive breeding site for the beetles. For *Ips*, the breeding site is cut green stems and larger limbs from within the plantation or nearby. Green material that is generated from winter through early summer and is greater than 3” in diameter presents the greatest risk. For RTB, the breeding site is fresh stumps.

Management Options: To prevent mortality from either of these beetles, avoid thinning plantations during drought or thin later in the growing season, such as August through October, when risk is lower.

Other Bark Beetles

Other pole-size conifers, besides pines, will on rare occasions experience similar mortality from bark beetles. Douglas-fir attacked by the Douglas-fir engraver, *Scolytus unispinosus,* is an example. It breeds in green stems and larger limbs of Douglas-fir, and may leave this material to attack nearby trees. Avoid creating large amounts of breeding material when drought-stressed Douglas-firs are nearby.

Winter storm damage - windthrow and stem breakage – also produces breeding material for bark beetles. Most damage resulting from these events has not involved the beetles mentioned above or occurred to young trees. Beetles such as the western pine and Douglas-fir beetles, which attack older, larger trees, are more likely to be involved. Consider the potential for damaging bark beetle activity whenever large amounts of green slash are created and susceptible trees are nearby.

Insects that Attack Shoots

The most damaging insects in this group attack pines and include: the western pine shoot borer (WPSB), *Eucopina (Eucosma) sonomana*, ponderosa pine tip moth, *Rhyacionia zozana*, and gouty pitch midge, *Cecidomyia piniinopsis*. The latter two insects are recognized for killing shoots, while WPSB more often reduces terminal shoot growth. Weevils in the genus *Pissodes* occasionally kill terminal shoots of pine and spruce, but reports of damage are rare in California.

Western Pine Shoot Borer

Recognition and Significance: Western pine shoot borer typically restricts its attacks to the terminal shoot (leader) of the tree and completes its life cycle without killing the terminal. Attacks on lateral shoots are less common but are more likely to kill the shoot. Ponderosa pine is the principal host, but Jeffrey and other pines are also attacked. WPSB's principal impact is reduced height growth. Loss of dominance by the terminal shoot and stem deformity also occur. Chronic infestations can have a significant impact on wood production over the life of a stand of trees, especially on more productive sites. Because shoots are rarely killed, damage may be overlooked. The sex pheromone of WPSB has been identified, synthesized, and used in various treatments to disrupt mating and prevent damage.

WPSB moths (fig. 10.6) emerge and begin flying in early spring, just as snow cover is disappearing from many sites. Eggs are laid singly on expanding terminal buds and shoots. One larva typically mines a shoot, but occasionally there may be two. Mines follow the pith and are packed with dark brown, somewhat resinous frass (fig. 10.7A). Larvae exit shoots in late spring near the lower end of the mine, leaving a small hole and resin droplet on the surface. They drop to the ground where they pupate and overwinter. There is one generation per year.

Figure 11.6 Western pine shoot borer moth. Length varies from ¼ to not quite ½ inch.

Infested terminals become stunted, causing needles to bunch together and shorten relative to needles on non-infested shoots (fig. 11.7B). The entire shoot may be impacted, or initial growth of the shoot may look normal, while later growth, i.e. younger needles closest to the top, are clearly impacted.

A B

Figure 11.7 Terminal shoots of ponderosa and Jeffrey pines infested by the western pine shoot borer. (A) Shoot cut open to reveal a WPSB mine, and (B) external symptoms of infestation.

Suspect WPSB whenever terminal shoots exhibit these symptoms. Moths can be caught in pheromone-baited traps, but otherwise are rarely seen. Larvae are off white with a tan to brown head capsule and can be found in mines during the spring. The best time to recognize and survey for damage, however, is after trees have finished height growth and damage is finished for the year, i.e. summer onward. Confirmation of WPSB is made by cutting into one or more symptomatic shoots and finding the characteristic mines.

Damage is first noticed when tree height is 3-4 feet and can continue for a couple of decades, or more. A good time to begin monitoring for damage is early in this period of susceptibility since a steady increase in damage is likely as a plantation grows. A single infestation results in a one-time loss of height growth of about 25%. Trees with the largest terminal buds are preferred for oviposition and may represent the best growing trees in a plantation. Multiple factors have bearing on the decision of when to control damage, including age of the stand, percentage of terminals infested, and cost of treatment(s) versus benefit. Studies indicate that the greatest benefit is achieved when stands are treated at a young age after reaching a certain level of infestation. Benefits of control drop off for stands over 20 years old, are considered negligible for light infestation levels (25% or less), and will be greatest for heavily infested (50% and higher) high value stands.

Management Options: Infestation levels can be reduced by use of a commercial product (MalEx™ ShootBorer) which utilizes the pheromone and a pesticide in a formulation that attracts and kills male moths. Treatment is applied by hand in the spring just before or as close to moth emergence as possible, which can be monitored . Thinning a plantation can cause the infestation level to increase significantly as damage is concentrated on fewer trees. To avoid this, application of the pheromone treatment in the spring following a thinning is recommended. This combination of thinning / pheromone treatment will help plantations to quickly grow through the time when they are most susceptible to damage. Because moths will reinvade a treated area, one or two additional pheromone treatments, two years apart, may be warranted.

Ponderosa Pine Tip Moth

Recognition and Significance: The ponderosa pine tip moth is one of several *Rhyacionia spp.* that mine buds and shoots of young pines, killing the shoots and stunting the growth of trees that are repeatedly attacked (fig. 11.8). As the name suggests, ponderosa pine is the principal host, although other pines including Jeffrey, lodgepole, and sugar pines may be attacked. Damage is predominantly on trees less than 6 feet in height on dry sites.

Figure 11.8 Trees and shoots damaged by the ponderosa pine tip moth.

Moths emerge in the early spring, overlapping with, but starting slightly later than WPSB emergence. Eggs are laid on elongating terminal and side shoots. Larvae are initially found externally on shoots, where they form a bubble-like shelter of silk and resin, and create a hole through which the shoot is entered for feeding. Eventually they stay within the shoot. Multiple larvae feed inside a single shoot, where they consume nearly everything, creating a maze of tunnels and frass (fig. 11.9).

Figure 11.9 Mines of the ponderosa pine tip moth within a killed shoot.

Needles on the shoot fail to develop and remain short (fig 11.8). Needle color begins to fade in late spring and becomes more noticeable as the summer progresses. An occasional larva will pupate in a shoot, but most will leave and pupate at the base of the tree in mid-summer. There is one generation per year.

Tip moth damage is often concentrated on individual trees and in certain areas of a plantation. It is easily recognized by the dead or dying shoots that are consumed on the inside. Slight pressure on a heavily mined tip causes it to crumble. Intact older dead tips may be present, but over time they disintegrate, leaving a resinous stub at the end of the damaged shoot. Larvae, present from late May through much of July, are orange-brown and develop a slight rose color as they mature (fig. 11.10). They are 10-12 mm (slightly less than ½ inch) when fully grown. Pupae are dark brown and roughly half this length.

Figure 11.10 (A) Young larva of ponderosa pine tip moth. (B) As larvae mature, the head and prothoracic shield lighten in color, and the body takes on a slight rose-colored tinge.

An accumulation of tip moth cocoons can be found at the base of infested trees at or near ground line. Cocoons are tightly lodged in gaps and crevices of the outer bark. They consist of loosely woven silk and dried resin, and depending on the time of year may contain pupae (late July through March / April) (fig. 11.11).

Figure 11.11 (A) Old cocoons on bark near ground level and (B) pupae of ponderosa pine tip moth.

Management Options: The sex pheromone of *Rhyacionia zozana* has been identified and shown to be effective at disrupting mating and reducing damage. However, no commercial products for control are currently available. The WPSB pheromone attracts males of *R. zozana*, so there is speculation that pesticide treatments containing it may control tip moth damage, but this has not been tested. While both moths can be found in the same plantations, significant damage from the tip moth is restricted to drier sites. Most trees quickly outgrow tip moth damage and the fastest growing trees appear to receive little damage from it. Any treatment that improves tree growth will help reduce damage.

Gouty Pitch Midge

Recognition and Significance: Midges in the genus *Cecidomyia* form pits beneath the bark of new shoots or live in exuded resin masses on pines and are known as pitch or resin midges. The gouty pitch midge, *C. piniinopsis*, primarily attacks ponderosa pine. Damage ranges from scarring to shoot dieback, depending on the level of infestation. Chronic infestations can deform trees and retard growth.

Confirming pitch midge as the cause of shoot dieback can be somewhat confusing because infested shoots are alive and then die after the insects have exited. There is a one generation per year. In the spring, tiny adult midges emerge from cocoons on needles and females lay eggs on expanding pine shoots. Eggs hatch and salmon-colored larvae enter new shoots where they develop in resinous pits just beneath the bark. The cocoons are distinctive (fig. 11.12), but neither the adults nor eggs are easy to find.

Figure 11.12 Cocoons of the gouty pitch midge.

Fully developed larvae are 4-5 mm (3/16 of an inch) long (fig. 11.13). Infestation may produce slight stem swelling, but shoots otherwise look normal and remain alive through the one-year period of infestation. In late winter, larvae exit the shoots and make their way to needles where they pupate. The previously infested shoots can continue to live or may die in the spring.

Figure 11.13 Gouty pitch midge larvae. (A) Within an infested shoot and (B) close-up.

Management Options: Trees differ in their likelihood of becoming infested and damaged. Damage is heaviest on trees with viscid or sticky shoots, a heritable trait. Trees with dry or waxy shoots can become infested, but damage is less (fig. 11.14). In most plantations, damage is unlikely to be severe and trees will continue to grow at a normal rate. Selectively removing damaged trees is an option, but only is recommended if height growth is being significantly impacted. Trees over 16 feet in height are unlikely to be damaged. Attempts to control the midge with pesticides have not proven successful. While it should be possible to breed resistant planting stock, low demand makes this impractical.

Figure 11.14 Ponderosa pines with different levels of attack by gouty pitch midge. The tree on the left has viscid shoots, while the tree on the right has dry shoots.

Insects that Attack Foliage

In general, this group of insects presents a limited threat to young trees. Insects with piercing / sucking mouthparts, such as aphids and scales, are unlikely to reach damaging levels. Populations of some other insects may reach damaging levels on occasion, but natural enemies – parasites and predators – play a significant role in controlling outbreaks and maintaining populations at endemic levels. Some of the more common insect defoliators are discussed.

Grasshoppers

Recognition and Significance: A small number of grasshopper species are a potential threat to seedlings and young trees up to a few years in age. Trees are not favored food, but grasshoppers will feed on and damage trees when their preferred food, green grasses and forbs, dries and becomes unpalatable. Endemic grasshopper populations are not a threat, but outbreaks can cause significant damage, including complete defoliation and mortality of young trees.

Grasshopper outbreaks are sporadic and difficult to predict. Similarly, outbreaks are not likely to be noticed until some level of damage is seen. Most grasshoppers have a one year life cycle and it is the older stages that damage trees by consuming needles and buds. By the time damage is noticed, there may be little that can be done during the current year. Control, if it is needed, is aimed at the next generation, which hatches in the spring. Young grasshoppers are the easiest stage to control and their numbers indicate the level of damage that may occur later in the season. Although they are easily recognized, young grasshoppers do not feed on trees, so look for them on adjacent vegetation.

Management Options: There is no established economic threshold for controlling grasshoppers in tree plantations. A logical approach, however, would be to survey grasshopper numbers at the time of damage to get an estimate of the density that is causing damage. The number of grasshoppers per square yard is a commonly used metric. Monitor grasshopper densities the following spring to determine if control is warranted.

Eliminating or reducing the levels of grasses and forbs in the spring will cause young grasshoppers to either starve or leave, reducing local populations. Alternatively, young grasshoppers can be treated with a pesticide to reduce their numbers. Because grasshopper populations may be an issue over a larger area, it is recommended that the situation be reported to and discussed with the County Agricultural Department.

Pine needle-sheath Miner

Recognition and Significance: The pine needle-sheath miner, *Zelleria haimbachi*, is a defoliator of 2 and 3 needle pines, including ponderosa, Jeffrey, and lodgepole pines in California. Outbreaks have periodically occurred in pine plantations where trees are 4 or more years old. Heavy defoliation can cause temporary growth loss and limited shoot dieback. Natural enemies play an important role in controlling populations.

Eggs are laid, one per needle, on current-year needles in late spring to mid-summer by female moths. They also may be laid on older needles, especially when populations are high and the complement of current-year needles has been greatly reduced by defoliation. Eggs hatch in summer and the first 2 instars of the insect are spent as a tiny, thread-like caterpillar feeding within a needle until the spring. Individual needle mines are barely visible with the naked eye and amount to insignificant damage (fig. 11.15).

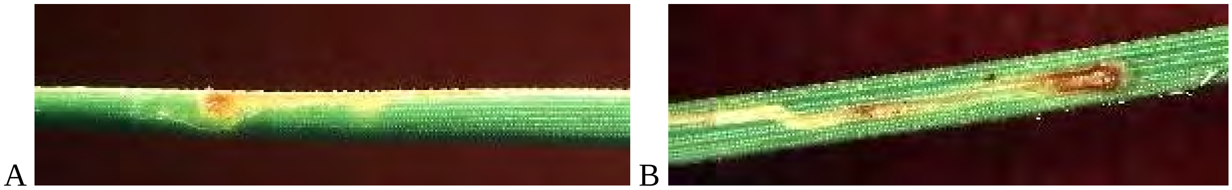


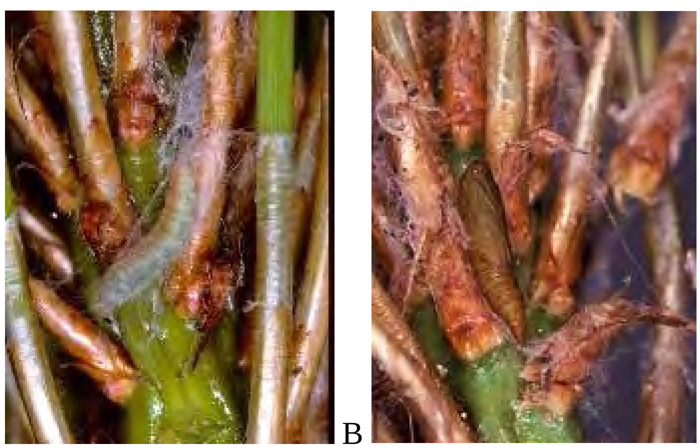
Figure 11.15 Close-up of mines of the pine needle sheath miner. The first instar larva mines along the edge (A) of a needle and then moves toward the center (B) during the second instar. Completed mines range in length from about 50-80 mm.

As new shoots and needles begin to elongate, caterpillars exit these mines and begin feeding on developing needles by chewing a round hole through the needle sheath and eating the bases of needles (fig. 11.16). This feeding begins in May and lasts about 3-4 weeks. Needles are severed and die before finishing elongation, and are easily pulled from their sheaths. Damage depends on the number of caterpillars feeding, and anywhere from a handful to all the needles on a shoot may be killed (fig. 11.17). Severed, green needles initially remain within the sheath, but eventually fade and begin falling out.

Figure 11.16 Holes mark where the pine needle sheath miner fed at the base of the needle fascicle.

Figure 11.17 Ponderosa pine shoot heavily damaged by the pine needle sheath miner.

During the sheath feeding phase, caterpillars are found on new shoots at the base of needles, along with silk webbing and frass. Caterpillars initially are tan, but take on orange and green overtones as they develop (fig. 11.18A). They reach a length of 12-13 mm (about ½ an inch). Pupae are half this length and found in silk webbing on damaged shoots in June (fig. 11.18B). Tiny white moths with tan markings begin flying in the later part of June and may be present into August.



A B

Figure 11.18 Pine needle sheath miner (A) larva and (B) pupa.

Outbreaks are not common and often are short-lived. Natural enemies and host quality both likely contribute to this. Heavy defoliation kills current year's needles, which are the preferred oviposition site for the next generation. If these needles are gone, eggs are laid on older needles, which presumably are less suitable for insect survival. Little information exists on impacts of defoliation, but what does exist indicates that most outbreaks are unlikely to cause significant damage. A rare, worst case would involve multiple years of defoliation.

Management Options: Direct control has been shown to be highly effective at reducing populations - insecticide treatment is applied when most caterpillars have exited mines and entered the sheath feeding phase, usually in the latter half of May. The synthetic pyrethroid insecticide esfenvalerate has been used successfully in aerial applications, but other insecticides are likely to be effective as well.

If direct control is being considered, an estimate of the population should be made by sampling trees in mid-late April when caterpillars are still in needle mines. Shoots, including the full complement of last year's needles, are collected from a subset of trees. On each shoot, a portion (e.g. 50%) of last year's needles are inspected for needle mines, which are relatively easy to see by April, but not before. The number of mines is counted and multiplied by the appropriate factor (times 2 if 50% of needles are inspected) to estimate the number of larvae per shoot that will enter the sheath mining phase. One or two caterpillars per shoot cause negligible defoliation. Slightly more, and defoliation begins to stand out. When numbers approach 10 caterpillars per shoot, defoliation is heavy. If most of the previous year's needles were killed, it will be necessary to look at the complement of needles from the year prior to that and to distinguish between old, unoccupied mines and those that contain caterpillars of the current generation.

White fir Sawfly and Douglas-fir Tussock Moth

Recognition and Significance: These two insects defoliate white fir in distinctly different patterns. Sawfly larvae restrict their feeding to old needles, while tussock moth caterpillars initially feed on young needles and then may feed on needles of all ages as the caterpillars mature. It has been noted that if their outbreaks coincided, this would have a devastating impact on trees since defoliation would be rapid and nearly complete. While this is plausible, it is not likely. Both insects feed on trees of all sizes, but defoliation is heaviest on the youngest trees. This distinction is more pronounced with the sawfly.

Outbreaks of the white fir sawfly, a *Neodiprion* species, have occasionally occurred in stands of white fir. Damage is limited for two reasons: outbreaks typically are short-lived, i.e. a year or two, and feeding is restricted to old foliage (fig. 11.19). Feeding starts in the spring slightly before or when new growth begins. While feeding on old foliage can be heavy, new foliage remains undamaged. A major outbreak occurred in northern California in the 1950s, but mostly minor activity has been noted otherwise.

Figure 11.19 Foliage damaged by the white fir sawfly. Newly flushed needles are untouched.

The sawfly has a one year life cycle. Adult flight, mating, and oviposition occur from October to early November. Females insert eggs singly into needles where they overwinter. Larvae hatch in the spring and feed gregariously. They are olive green, essentially hairless, and reach a length of slightly less than an inch at maturity (fig. 11.20). In contrast, tussock moth, O*rgyia psuedotsugata*, caterpillars are quite hairy and do not feed gregariously. By July, sawfly larvae stop feeding and begin to leave trees to pupate in the duff. An occasional pupa may be found among foliage.

Figure 11.20 White fir sawfly larvae.

Outbreaks of the Douglas-fir tussock moth are much more frequent and extensive than those of the sawfly, occurring somewhere in California on average about every 7-10 years. White firs of all ages can be heavily defoliated and put at risk for mortality. Douglas-firs receive little, if any defoliation. In the past, treatments to control outbreaks were applied over large areas, but it is now recognized that heavy defoliation and damage is limited to local hot spots within larger outbreaks. White fir stands on ridge tops, upper slopes, and poorer sites are likely to receive the heaviest defoliation. Because trees can be killed or damaged by a single season of heavy defoliation, early detection and evaluation of building populations is critical.

Endemic populations of the tussock moth are virtually undetectable, except through monitoring with pheromone-baited traps. Depending on the area, the USDA Forest Service or CAL FIRE may be monitoring tussock moth populations. Such efforts provide area-wide information on population fluctuations and can be a cue of when to look more closely for tussock moth. Trap results can indicate if an outbreak is likely, but do not predict where it will occur. Aside from extensive sampling, a next best option for early detection is to keep an eye out for defoliation (fig. 11.21) or any other signs of the moth.

Figure 11.21 Light defoliation of white fir caused by the Douglas-fir tussock moth. Brown needles are partially eaten.

This can be done during normal duties and by planned visits to high risk sites. The tussock moth has a one year life cycle. Caterpillars (fig. 11.22), present from June through most of July, and egg masses (fig. 11.23), laid on foliage from late summer through October, are the most visible stages of the insect. Finding these or other evidence of the moth would be reason to request a local evaluation, which is best done by an entomologist or forest pest specialist.

Figure 11.22 Douglas-fir tussock moth caterpillars come in different color variations. The distinctive tufts and other markings become more pronounced as the larvae mature.

Figure 11.23 Douglas-fir tussock moth egg mass and cocoon.

Management Options: Direct control of the sawfly might be considered for an outbreak of multiple years that coincided with other damage or stress to produce significant impacts. The 1950s sawfly outbreak was easily controlled with an insecticide, although natural enemies likewise exerted control in untreated areas. While direct control of the tussock moth is feasible, an evaluation is essential to determining an appropriate course of action. Evaluations on state and private lands are conducted by CAL FIRE; on federal lands, by the USDA Forest Service.

Diseases

Most diseases of significance in plantations are found on trees of all sizes and are a component of the environment in to which young trees become established. Direct control of forest pathogens is rarely an option, but there are management strategies that will reduce the incidence or impact of many tree diseases.

Many bark beetles and some woodborers and weevils attack trees under stress, including diseased trees. Some of these associations are well studied, while others have been observed but not rigorously documented. If cambium-feeding insects are attacking a tree, the possibility of disease and other causes of stress should be investigated as well. The primary agent impacting the tree is deduced based on what is known of the organisms or other factors involved.

Root Diseases

Heterobasidion (Annosus) Root Disease

Recognition and Significance: Most conifers in California are potential hosts for one of two fungi that cause Heterobasidion root disease. In live trees, the pathogen acts as either a decay that weakens root systems or as a root disease capable of girdling and killing trees. In the root systems of stumps or dead trees, the pathogen can persist for up to fifty years as a saprophyte. Young trees are infected and killed when their roots contact the roots of an infected stump or nearby live or dead tree. Once a tree is infected, the pathogen can grow and spread to adjacent live trees via underground root-to-root contacts. If the dead, infected roots in the soil are large and extensive, the pathogen can persist on site and kill young trees for decades, creating an opening that is difficult to reforest.

Most openings or "disease centers" caused by Heterobasidion root disease are found in relatively pure ponderosa or Jeffrey pine forests, or true fir forests composed of white or red fir. Another characteristic of these centers is the presence of a single or multiple large infected stumps. The diseases in pine and fir are different both in terms of the species of fungus that causes them and the damage done. Live pines are infected by *Heterobasidion irregulare* (formerly known as the "p" type of the fungus) and experience cambial girdling and mortality, whereas true firs are infected by *Heterobasidion occidentale* (formerly the "s" type of the fungus) which causes wood decay in mature trees and may kill young firs. Diseased mature true firs are subject to windthrow. Stress resulting from infection by either fungal species often leads to increased mortality from bark beetles, particularly during drought. Strategies to manage the disease in pine and true fir are slightly different. Note that the host specificity that is exhibited by *Heterobasidion spp.* in live trees does not apply to cut stumps. From a practical standpoint, *H. occidentale* can infect a pine stump and subsequently move to a live fir. Movement of *H. irregulare* from a fir stump to a live pine, however, is unlikely.

Management of Heterobasidion root disease is a matter of recognizing risk and implementing preventative strategies. Tree failure can be a significant risk to people and structures in all forest types where the disease occurs. On timberlands, mortality of young trees is primarily an issue in pine, especially on drier sites that are naturally suited to support a high percentage of pine. Such sites may have a history of Heterobasidion root disease and thus be recognized as higher risk for the disease. Aside from site conditions, larger pine stumps are an essential component of risk. A freshly cut stump surface can be an important route for the pathogen to become established on site. Without large pine stumps to saprophytically harbor the pathogen, risk is nil.

Heterobasidion root disease can be diagnosed by a variety of signs and symptoms. One key symptom is the association of dead young trees with larger stumps. Fruiting bodies (conks) (fig. 11.24) of *Heterobasidion* spp. often can be found within old stumps or on the roots of killed seedlings and young trees. A perfectly formed conk is a semi-circular shelf with a gray to brown top and an off-white pore surface on the bottom. Many conks, however, take on a more amorphous shape that conforms to their substrate and the space in which they developed. They vary in size from less than an inch to many inches across.

A B C

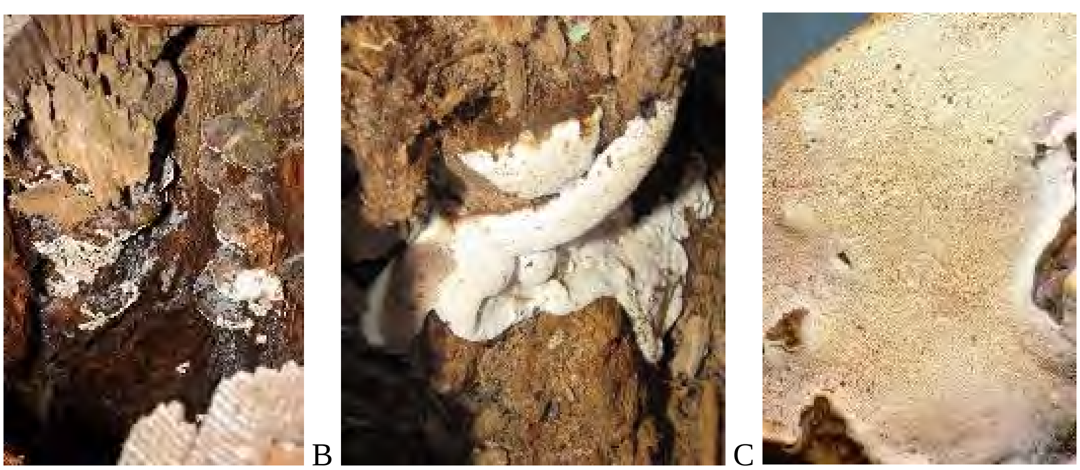


Figure 11.24 Conks of *Heterobasidion occidentale* from white fir. (A & B) In a stump, and (C) close-up of the lower pore surface.

They typically are hidden from view and must be revealed by removing duff and soil around the root collar or excavating decayed stumps. Wood with advanced decay is straw yellow, separates in a stringy or laminate fashion, and may have elongate white pockets and small black flecks (fig. 11.25). The roots of dead seedlings and young trees are discolored brown, often resinous, and may have tiny "popcorn" conks (fig. 11.26) attached.

(A) (B)

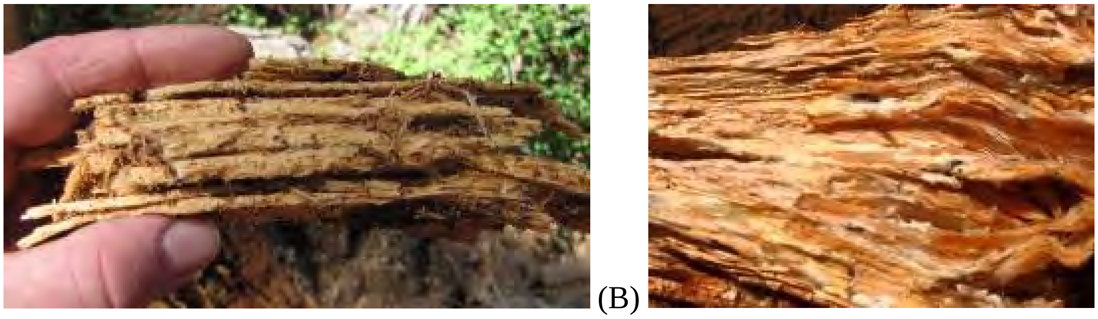


Figure 11.25 Lower stem and root wood of a white fir decayed by *Heterobasidion occidentale* illustrating (A) laminate separation and (B) white pockets and black flecks.

Figure 11.26 Popcorn conks of *Heterobasidion irregulare* at the root collar of a young ponderosa pine killed by the fungus.

In mature stands, openings (disease centers - fig. 11.27) are created by outwardly expanding mortality of trees over the course of many years. Trees near the center of the opening have been dead the longest, while those on the edge may exhibit symptoms or be dying. Trees with advanced disease have thin, chlorotic crowns. Crowns thin from the bottom up, so the top of the tree may look relatively normal. It may be possible to find roots or portions of the root crown that have been killed by disease. Phloem turns brown, underlying wood may have light brown streaking, and areas of resin accumulation are common in both wood and bark. Tree reproduction within disease centers is poor because seedlings and young trees are killed. Often there are large, old stumps in the disease center that suggest the pathway by which the opening was initiated. Black stain root disease causes similar crown symptoms and openings, but rarely kills young pines and produces very different signs within infected trees.

Figure 11.27 Heterobasidion root disease center in a ponderosa pine stand.

Management Options: When cutting live pines on high risk timber sites, stump surfaces can be treated with a borate fungicide to prevent colonization by *Heterobasidion* spp. Small stumps, i.e. less than 14 inches in diameter, present little risk for Heterobasidion root disease and can be left untreated. Stumps should be treated immediately or as soon as possible after cutting. If two days pass, the borate application will be ineffective. A benefit from treating true fir stumps on timber sites has not been proven for a variety of reasons: the pathogen is known infect true firs via other routes, infection is believed to be more common in true firs, and the impacts from infection are slower to develop in true firs versus pines. On sites where there is risk to people or infrastructure from tree failure, consider treating stumps of all conifer species down to a 3-inch diameter.

Black Stain Root Disease

Recognition and Significance: Black stain root disease, caused by the fungus *Leptographium wageneri*, occurs in several pine species and Douglas-fir. Although trees of all ages may be killed, it is not a common disease of young pines. Pole-size and larger Douglas-firs are more readily infected and killed, especially in single-species plantations. Unlike *Heterobasidion* spp., *L. wageneri* does not persist well as a saprophyte. Hence, if an infected stand is cut and replanted, seedlings have limited exposure to the pathogen. As plantations age they become more susceptible to disease. Plantations of Douglas-fir apparently reach a susceptible age sooner than those of ponderosa pine.

The fungus is moved from one location to another by insect vectors, i.e. certain root-feeding bark beetles and weevils. Thinning or other disturbance in a plantation can attract vectors and result in the fungus becoming established. It then can move from tree to tree through root contacts and grafts, as well as insect transmission. Once established, there are no proven methods for slowing or stopping the disease. There are three different varieties of the fungus and the variety that infects Douglas-fir will not infect pines and vice versa. Thus, planting non-host tree species within a disease center is an option.

Recognizing black stain is usually straight forward. It is easiest to diagnose in dying or recently dead trees, but can be difficult to diagnose in trees that have been dead for a few months or more. A progression of tree mortality over time (disease center) is one clue, although individual dead or dying trees are also common, particularly in Douglas-fir. Locate recently dead trees or, even better, nearby trees with thin crowns (fig. 11.28) or yellowing needles. Advanced black stain root disease often causes a well-defined area of resin streaming on the bark surface at the base of the main stem (fig. 11.29).

Figure 11.28 Douglas-firs with advanced crown thinning due to black stain root disease.

Figure 11.29 Resin streaming at the base of the main stem associated with black stain root disease on Douglas-fir.

If the disease is the cause, a characteristic stain will be found in the sapwood beneath (fig. 11.30). Use a long-handled axe to cut into the wood. The stain is dark brown and usually, but not always, resinous. In cross-section, it looks like a blotchy arc that roughly follows the curves of the outer growth rings. In longitudinal-section, it looks like dark brown streaks coming up from the roots. Blue stain (fig. 11.31) is also found in dead and dying trees, but it is bluish grey, usually not resinous, and is radially oriented in cross section. A lack of resin streaming on the bark does not mean that black stain is absent. Checking the sapwood around the base of the tree and on larger roots may still yield stain. Once a tree dies, the invasion of the wood by other microorganisms and insects makes the stain more difficult to recognize.

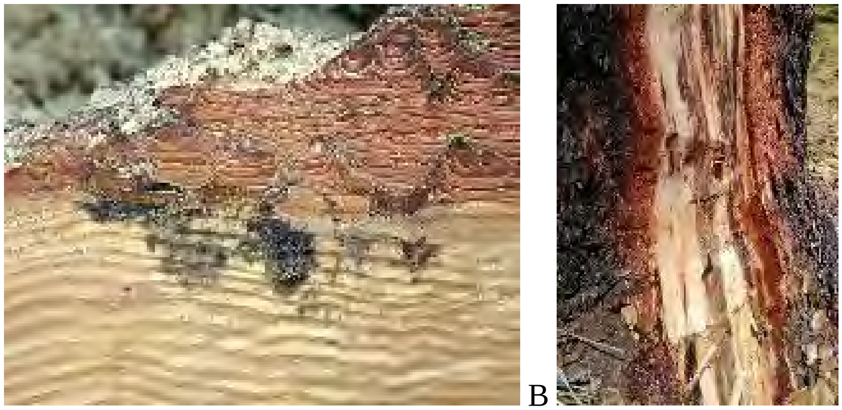


Figure 11.30 Typical stain produced by black stain root disease in the lower stem of a ponderosa pine. (A) In cross-section and (B) longitudinal-section.

Figure 11.31 Blue stain.

Management Options: Reducing the likelihood of disease establishment is the preferred option for plantations that have no evidence of black stain root disease. Studies have shown that the timing of thinning and other disturbances is important to establishment. Thinning during the spring and the months leading up to it create the greatest risk of disease establishment, while summer has the lowest risk. This is because spring is a peak flight period for insect vectors as well as having cool / moist soil conditions which favor infection. Fall and winter have elevated risk because cut or injured host tissues remain fresh and attractive to vectors into spring months.

If seedling survival is expected to be good, it may be desirable to avoid or minimize future thinning by planting at a lower density. On sites that will support it, consider planting non-host tree species or a mix of host and non-host species.

Other Root Diseases

Port-Orford-cedar root disease (POCRD), caused by *Phytophthora lateralis*, and Armillaria Root Disease, caused by *Armillaria spp.*, can both kill young conifers, but are primarily of concern for other reasons. POCRD is a non-native invasive pathogen that is spread via infested soil and water. Port Orford cedar trees are highly susceptible to this lethal disease. Timber operations and other human activities have contributed to disease spread and are primary routes by which long distance spread occurs. Regulations and best management practices designed to prevent the spread of POCRD are available and should be known to all who manage lands with Port Orford cedar.

For the most part, Armillaria root disease is a minor issue in California's conifer forests. This is mainly because the most virulent species of Armillaria do not occur in California. Most observed conifer mortality from the disease has occurred in situations where living, large diameter oaks have been cut adjacent to conifers. The residual oak stumps and roots become a reservoir for the pathogen, which then infects and kills conifers. Mortality is typically limited to the area immediately around the cut oak. Significant mortality was observed in one situation where all oaks were cut with the intent to convert to all conifers. Conifer mortality is less likely when large oaks senesce and die naturally.

Dwarf Mistletoes

Recognition and Significance: Dwarf mistletoes, *Arceuthobium* spp., infect most conifer timber species in California, including species of true fir, pine, spruce, Douglas-fir, and hemlock, but not incense cedar. These parasitic plants rarely kill trees, but can have a profound impact on growth or lead to secondary attack by other insects and pathogens. The greatest impacts occur where site conditions are less than optimal and added stress from dwarf mistletoe further weakens trees.

Recognition of dwarf mistletoe is simple, but it is not unusual for the disease to be overlooked or underestimated by land managers. Branch swelling and formation of witches' brooms (see below) are common symptoms. Dwarf mistletoe plants (fig. 11.32) or their remains confirm the disease. Propagation is by seeds which are forcibly ejected by female plants in the late summer and fall.

Figure 11.32 Female dwarf mistletoe plants on lodgepole pine.

They only go a short distance, tens of feet or less, and have a sticky coat which adheres them to whatever they land on. New infections are thus initiated on the same tree or nearby trees. Birds and animals can transport seeds longer distances. Infection only occurs on young stem tissue, i.e. less than 5 years old, on an appropriate host. Mistletoe growth is initiated within the stem, and plants begin to emerge 2-5 years after initial infection. Swelling (fig. 11.33) of the stem is typical, and older branch infections lead to the development of witches' brooms (fig. 11.34). Plants are small, no more than a few inches tall, green to yellow in color, and sometimes difficult to see. They eventually detach, leaving behind small round structures embedded in the bark called basal cups (another way to confirm the disease). Detached plants often litter the ground beneath heavily infected trees.

Figure 11.33 Branch swelling from dwarf mistletoe on lodgepole pine.

(A) (B)

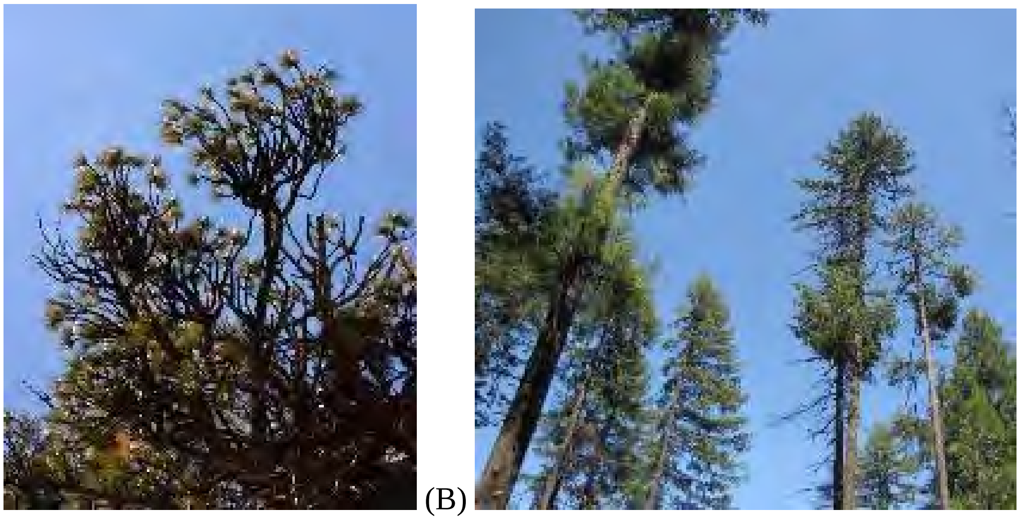


Figure 11.34 Witches brooms of dwarf mistletoe in (A) ponderosa pine and (B) Douglas-fir.

Individual infections have a limited effect on the tree and it takes the cumulative impact of numerous infections, acquired over time, to have a significant impact. Disease severity rating is based on the amount of the tree crown that is infected. Infections remain active as long as the infected tissue remains alive. Infections are likely to spread and intensify over time, with stand structure having a significant influence.

Bole infections, which are less common than those on branches, are of additional concern because they can lead to future stem defects. Several aspects of dwarf mistletoe biology are important to disease management: dwarf mistletoe species are highly host-specific, i.e. only one or a few closely related hosts are infected by each *Arceuthobium spp*.; spread of the pathogen is slow; and dwarf mistletoes are obligate parasites that only survive on living hosts.

Single-species, multi-storied infected stands are a worse-case scenario. If young trees are overtopped by infected overstory trees, the chances of infection are high because mistletoe seeds will rain down upon the trees below. Single-species, single-storied infected stands fare better, especially if height growth is rapid. Upward spread of dwarf mistletoe within a tree crown is slow. If no mistletoe seeds are coming from above, this allows fast growing infected trees to outpace this upward spread of the pathogen and thus produce substantial amounts of disease-free crown. A mixture of tree species slows the spread of dwarf mistletoe, but many infected sites are not well suited to grow a mixture of trees or are difficult to regenerate as a mixture.

Management Options: Tree harvest and reforestation practices can greatly influence future levels of dwarf mistletoe within a stand of trees. Infected single-species stands are typically regenerated using even-aged management, i.e. clearcutting, group selection, seed tree, and shelterwood. Complete removal of infected overstory trees prevents the transfer of disease to regeneration; if residual seed and shelter trees are present, these are removed as soon as is practical. The configuration and size of openings can be adjusted to minimize the likelihood of disease entering from adjacent infected stands. Align edges of the opening with natural barriers to disease spread, such as ridges, rock outcroppings, groups of non-host trees, etc. When barriers are absent, larger openings will slow disease spread to the interior of the opening. Thin infected plantations to improve tree growth and maintain a canopy of uniform height. Remove slower growing trees, especially ones with infection.

Mixed conifer stands are less likely to have high levels of dwarf mistletoe. When they do, it usually is in pockets where host trees are concentrated. With minor exceptions, dwarf mistletoe species are limited to a single host genus, and within a genus, they are limited to one or a few species. Pines, Douglas-fir, and true firs all are infected by separate species that will not cross over to another host genus. Ponderosa pine shares dwarf mistletoes with other pine species, but notably does not share a dwarf mistletoe with sugar pine. A single species of dwarf mistletoe infects true firs in California, but different (sub-generic) forms of the mistletoe mean that the pathogen only occasionally spreads between red and white firs. These host differences provide natural barriers to disease spread and can be utilized when harvesting and regenerating mixed conifer sites.

Rusts

White Pine Blister Rust

Recognition and Significance: This non-native invasive disease, caused by the rust fungus *Cronartium ribicola*, is a serious threat to white pines - sugar, western white, whitebark, and limber pines - in California. Resistance to the disease is low. Young trees often are killed, while mature trees may be damaged but survive. The blister rust pathogen requires an alternate host to complete its life cycle and past control efforts were aimed at eliminating a principal alternate host, *Ribes* spp., without success. Currently, efforts by the USDA Forest Service in California are aimed at identifying and breeding resistance in sugar pine, which may be the best option for protecting regeneration. Federal, state, and private land managers cooperate in the program.

As with many pathogens, weather can significantly influence the infection process. Widespread infections typically occur during "wave years" when environmental conditions are favorable, i.e. high humidity in late summer or early autumn. Infection occurs through a needle and progresses to the stem where a canker is produced. Cankers take time to develop, but many will eventually girdle the stem, killing the distal portion of the stem (fig. 11.35). Cankers are spindle-shaped (fusiform) with cracked and sunken bark (fig. 11.36). Bright orange spores may be present within cankers in the spring. Limited numbers of infections may occur most years, but damage from infections that occurred during wave years can be dramatic.

Figure 11.35 Western white pine with upper stem girdled by blister rust.

Figure 11.36 Cankers of white pine blister rust on sugar pine stems.

Older trees are protected somewhat because a high proportion of their stem tissue is not associated with needles and thus can't be infected. Just the opposite is true for young trees. Trees that survive dieback will have evidence of cankers and may have thin, ragged crowns depending on the severity of damage. Young trees can be killed directly by a canker on the main stem, or may die from the cumulative effect of cankers throughout the crown.

Management Options: Except for the extreme southern end of the range of sugar pine, in and south of the Tehachapi Mountains, most of the state's white pines are potentially exposed to the pathogen, although damage has varied across sites. In areas where disease incidence is low to moderate, sanitation thinning and pruning may be beneficial. Target the most damaged trees for removal during thinning. Pruning infected branches from lightly infected trees can improve their chance of survival provided branch cankers are no closer than 4 inches from the main stem. Prune from the bottom of the crown up starting with infected branches. Removal of the lower most non-cankered branches may also be beneficial, but no more than 50% of live branches should be removed overall. Once an infected tree or branch is cut, the pathogen dies as well. Individual trees which show limited, slow, or no disease development relative to other trees in the area may be candidates for resistance testing. For sites where disease has been severe, consider regenerating with non-host tree species.

Western Gall Rust

Recognition and Significance: Western gall rust is a native disease caused by the fungus *Endocronartium harknessii*. It infects many species of hard pines, but is most common on Monterey, lodgepole, and ponderosa pines. Like blister rust, heavy levels of infection occur during wave years and young trees are impacted the most. Mortality, however, is rare and restricted to the youngest trees. No alternate host is needed to complete the life cycle. The disease is most common in areas where moist air favors infection. Some higher levels of disease in ponderosa pine are seen in the northern Coast Range and west side of the northern Sierra Nevada.

Infection occurs on young shoots, producing a persistent, globose gall that gradually increases in size over time. Yellow/orange spores are produced by galls in the spring and early summer (fig.11.37). Branch ends distal to the gall may die, either directly from the expanding gall or from secondary pests that invade it. Infections on the main stem of young trees may persist for years, necrose and be invaded by secondary pests. This produces a weakened, cankerous area on the stem of the mature tree that is subject to failure (fig.11.38).

A

B


Figure 11.37 Western gall rust (A) on Monterey pine and (B) producing spores on ponderosa pine.

A

B


Figure 11.38 Stem infections of western gall rust that occurred when the trees were young and continued to impact the trees throughout their lives. (A) Canker on Monterey pine. (B) Stem failure at an infection site on ponderosa pine.

Management Options: To avoid future impacts, remove young infected trees from plantations, especially ones with high levels of disease or a main stem infection. Consider planting other conifers in areas with high risk for disease (riparian areas, around meadows, and in other areas where moist air collects).

Needle Diseases

Most needle diseases are of minor importance because widespread infection occurs infrequently and impacts a limited complement of needles. Specific environmental conditions are needed for infection and pathogen biology is tuned to take advantage of this, typically during a once-per-year window of suitability. Trees that experience a one year episode of infection and needle loss typically recover well. The youngest trees may be impacted the most, but also would be expected to recover. Recovery may be slower for trees suffering from other stresses. Rarely does widespread infection occur in consecutive years.

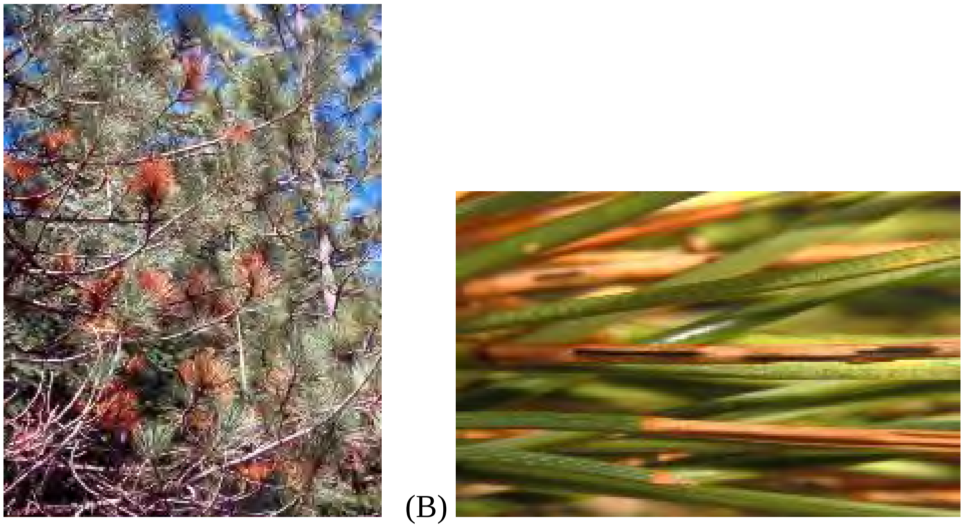
There are some exceptions to this scenario. Red band needle blight, caused by *Mycosphaerella pini*, can be particularly damaging to Monterey pine planted on the northern California coast outside of its native range. Another exception is Elytroderma disease, caused by *Elytroderma defomans*. In addition to causing needle loss, the pathogen can persist within branches and result in long term impacts.

Elytroderma Disease

Recognition and Significance: This disease of pines primarily impacts ponderosa and Jeffrey pines. Like other needle diseases and rusts, widespread infection occurs during wave years. Current year needles are infected and die the following year. Widespread fading of these needles in the spring (fig. 11.39A) is what garners the most attention, but unlike other needle diseases, trees that have previously been infected harbor the fungus within branches, buds and growing tips, causing other symptoms and impacts, including poor needle retention, witches' brooms, and reduced growth.

Initial infections are from airborne spores that infect through needles. Once the pathogen is established in a branch, it continues to grow along with the branch and can infect new needles directly. Branch infections thus allow the pathogen to colonize new needles when environmental conditions do not favor airborne infection. These infections also lead to witches' brooms. Internal infections persistent on a branch, but do not spread to uninfected portions of the crown.

Fruiting bodies of the fungus are dull black, elongate structures (fig. 11.39B) that may or may not be present on needles that died in the spring. Witches' brooms are relatively globose, compact, and have up turned branches.



(A) (B)

Figure 11.39 Jeffrey pine infected by *Elytroderma* deformans. (A) Needles fading in the spring and (B) with fruiting structures.

In contrast, brooms from dwarf mistletoe are more spread out, have greater branch swelling, and often have mistletoe plants. One of the most useful signs for identifying Elytroderma is the presence of brown necrotic flecks within the inner bark of infected twigs (fig. 11.40). Cut into tissue that is at least 3 years old to see it.

Figure 11.40 Brown necrotic flecks in the inner bark are a sign of Elytroderma disease.

Sites that favor a higher frequency of infection include areas around lakes, in canyons, and north-facing slopes. If mature trees in such areas show symptoms through much of their crown, this indicates repeated infection and high hazard for the disease. Young trees in high hazard areas may experience growth loss, deformity, and have little opportunity for disease-free growth during their life.

Management Options: Tree mortality from Elytroderma disease is unlikely, but may increase susceptibility to other pests. Little can be done to prevent the disease, but removal of highly impacted trees and thinning should improve the growth of residual trees. Offsite pine plantings should be avoided.

Non-host conifers can be favored on high hazard sites. Needle loss can be widespread following wave years, but most trees outgrow the effects of disease on sites where infection frequency is low.

Cankers

A canker is a localized area on stems or branches where the cambium and adjacent bark has died, typically from fungal or dwarf mistletoe infection. Cankers can also be caused by abiotic factors, including weather extremes, fire or mechanical damage. In contrast, the term “canker” is not applied to insect damage.

Fungi that cause cankers are not usually aggressive pathogens, but can be damaging when the host is under stress. They enter susceptible tissues through wounds or other openings in the bark, such as branch stubs. Most canker fungi are restricted to bark and cambium tissue and do not penetrate the wood. As the dead tissue dries and shrinks, it becomes sunken relative to surrounding live tissue (fig. 11.41). Eventually the dead bark is sloughed off and wood may be exposed. Callus forms at the edge of the canker and may close the wound with time, unless the damaging agent girdles the stem or continues to expand. Secondary organisms may colonize the killed tissue.

Figure 11.41 Phomopsis (*Diaporthe*) canker on Douglas-fir.

Canker diseases are not a significant threat to young conifers, but two fungi, *Diaporthe lokoyae* and *Dermea pseudotsugae,* are notable for causing cankers on young, stressed Douglas-fir, especially those stressed by drought. These two fungi can girdle and kill stems. Most damage is limited and repairable by the tree, but the youngest trees may experience significant dieback or be killed. Thinning and vegetation control can help ease drought stress. Chronic dieback of Douglas-fir is a good indication the site is better suited to more drought-tolerant species.

Pitch canker, caused by *Fusarium subglutinans*, sp. *pini*, is an invasive disease primarily restricted to pines growing near the coast. Serious damage has occurred in natural stands of Monterey and Bishop pines, and to a lesser extent knobcone pine. Young trees can be killed outright, while older trees experience dieback and may be killed by bark beetles. Although resistance occurs within native populations and damaged trees can recover, significant impacts still take place, especially in areas where the disease is recently introduced. Visit the Pitch Canker Task Force website (http://ufei.calpoly.edu/pitch_canker/index.lasso) for information on managing the disease and preventing its spread. Although work has been done to develop resistant stock, none is commercially available.

Phytophthora ramorum, the cause of sudden oak death, is another invasive pathogen that occurs near the coast, causing a wide range of impacts on trees and other plant species. Although direct impacts to conifers are minor, the disease has caused significant changes to some native ecosystems. Federal and State quarantines, and a Zone of Infestation established by the California State Board of Forestry and Fire Protection, are designed to prevent disease spread via human activities. See the California Oak Mortality Task Force (COMTF) website at www.suddenoakdeath.org for more information.

Vertebrate Pests

What is a vertebrate? Put simply, it's any animal with a backbone including fish, amphibians, reptiles, birds and mammals. What is a vertebrate pest? A pest can be defined as any organism creating an unwanted condition, i.e. invasive fish eating native fish; a rattlesnake in a wood pile; bird droppings on a park bench; or a roof rat living in an attic. In a forest condition, it usually means an animal or population of animals that is creating an undesirable condition to negatively impact a reforestation outcome.

Vertebrates (wildlife) are a natural, vital and desirable component of a healthy forest. They provide vital functions in dispersing mycorrhizal fungal spores throughout the forest floor (some voles and squirrels); disperse conifer seeds (birds and many rodent species); aerate soil and recycle soil nutrients (pocket gophers); and recycle plant nutrients (ungulates).

However, there are times when, for a variety of reasons, vertebrate populations may inhibit reforestation efforts requiring some level of human intervention to minimize negative impacts. As with any pest management scenario *one size usually does not fit all* situations thus requiring a thoughtful analysis of the impact, a review of management options, and diligence in application and monitoring. The science of Integrated Pest Management (IPM) has emerged since the first printing of this publication back in the early 1970s when most vertebrate pest management strategies focused solely on lethal options calling for the removal of the animal(s). The strategy back then was simply "*no animals….no problem.*" Since then, political and social realities have changed, causing forest managers to address pest management scenarios very differently, resulting in more thoughtful…and challenging…ways to address vertebrate pests.

This section provides vertebrate management strategies for the 21st century as forests and their managers face the reality of increased droughts, wildland fires, urban encroachment, and needs to protect threatened and endangered species.

Pocket Gophers (*Thomomys* spp.)

There are five recognized species of pocket gophers in California:

- Mountain pocket gopher (*Thomomys monticola*) occurs in the Sierra Nevada above 5,000’ from Fresno County north to Shasta and Lassen Counties.
- Western pocket gopher (*T. mazama*) found in wet meadows and grasslands of the Klamath and western Cascade Ranges.
- Northern pocket gopher (*T. talpoides*) occurs from Mono County north into Alpine, eastern Sierra, eastern Plumas, Lassen, Modoc and eastern Siskiyou counties where it is abundant in juniper habitats.
- Townsend’s pocket gopher (*T. townsendii*) found only in the western portion of Honey Lake Valley in alkali desert shrub.
- Botta’s pocket gopher (*T. bottae*) is by far the most widely distributed pocket gopher species in California occurring in all habitats except the eastern Sierra Nevada and portions of Lassen, Modoc and Siskiyou counties above 5,000’. This species is responsible for most damage caused to both agricultural and forest trees. Optimal habitats are perennial meadows, and grass and forb stages of most riparian deciduous and conifer forests. They are less common in mature stages of forest habitats. The focus on this portion of the chapter will be on Botta’s pocket gopher.

Pocket gophers (fig. 11.42) are so named because of the fur-lined, external cheek pouches used to carry food back to their cache. They are herbivorous, feeding mainly on roots, tubers, bulbs, stems and leaves of forbs and grasses. They can and do damage young forest conifer seedlings (fig. 11.43). They prefer to forage from underground tunnels where they can chew on roots in tunnels and may pull entire plants into the tunnel (fig 11.44). During winter they build surface tunnels above the ground through the snow to forage.

Figure 11.42 Pocket gopher.

Figure 11.43 Pocket gopher damage.

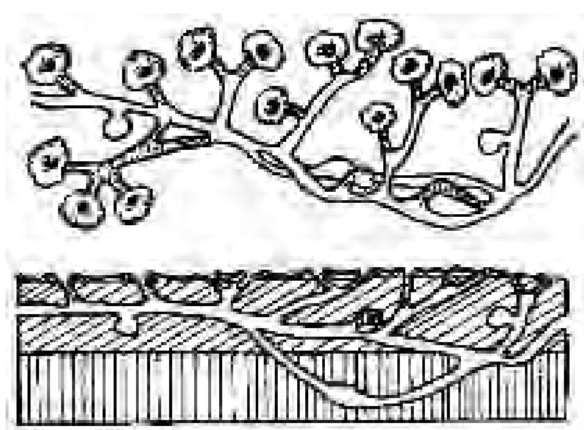


Figure 11.44 Example of a pocket gopher burrow system.

Reproduction and Life Traits: Pocket gophers nest in their burrows with deep chambers excavated for nurseries (females only). Litters are born in the spring with juveniles dispersing and expanding their tunnel systems. Males are larger than females. Males grow throughout their lives, whereas females stop growing after their first pregnancy, so older males can be much larger than females. Pocket gophers live in small, local populations, spending almost their entire lives underground in their network of burrows (fig. 10.44). Pocket gophers are solitary animals that defend their tunnels from marauders from intersecting tunnel systems in search of food. Consequently, each tunnel has one resident animal (except when a female is rearing her young) at a time. Pocket gophers do not hibernate and are active throughout the year.

Symptoms, Signs and Significance of Damage: The greatest risk to conifers from pocket gopher feeding damage occurs in the early stages of reforestation when the trees are at their smallest stage. Gophers will eat the roots and main stems of seedlings leaving the tops dead. During winter months, they strip twigs and bark from tree parts buried in snow. After snow melt, long winding strips of soil on the surface show where pocket gophers had tunneled and backfilled with soil. They often kill trees in the first three years of planting and in severe cases can affect the stand's ability to achieve regulatory stocking standards.

Management Options: Like all pest management strategies, diligence is required to detect and monitor pocket gopher activity centers. Addressing a *potential* problem often results in less time, energy and costs being needed to resolve the problem later.

There are few viable, non-lethal options to address pocket gopher damage to conifers. Fencing, both above and below ground, has not proven effective in minimizing damage as gophers can dig beneath, and climb over, most fences. Live trapping pocket gophers only results in moving the problem to a new location.

Lethal options include 1) predator attraction; 2) trapping; 3) toxic baits; and 4) fumigants.

1. Predator attraction can be achieved by leaving or providing structure adjacent to the planting site. Trees, artificial perches and snags can provide sites from which predatory birds can hunt for gophers. However, once a predator captures and consumes a gopher its dietary requirements will be addressed for some time until the animal needs to hunt again. Though predators will eat pocket gophers, they most likely will not achieve economic control without the aid of other management options.

2. Trapping is an effective way to reduce populations while simultaneously monitoring efficacy. Trapping is only effective if the effort is given the time required to: 1) place sufficient number of

traps per unit area to capture many animals simultaneously; 2) check the traps daily; and 3) relocate a trap to another burrow after an animal has been captured.

3. Toxic baits provide a relatively time conserving approach to covering large areas, but do not provide as quick and direct an evaluation of efficacy as does trapping. Toxic baits are placed underground in active burrows and are reliant on the animal consuming ample amounts to deliver a lethal dose. Bait acceptance can be affected by the composition of the bait, age and freshness of the bait, and soil moisture which can be absorbed by the bait causing it to dissolve or mold.

4. Fumigants can be effective if used properly. Soils need to contain some moisture to minimize venting of fumigant gases through soil pores; since pocket gophers do not hibernate, fumigants may prove useful throughout the year if soil conditions are right. Several types of fumigants are available:

    - Incendiary devices (smoke bombs, flares) often release sulfur gas, asphyxiating an animal below ground. Caution needs to be exercised during dry months when grasses may ignite.

    - Carbon Monoxide gas has been legal to control fossorial (below ground) pests since 2012. Both commercial and self-designed devices have been developed to deliver CO gas to burrows.

    - Aluminum Phosphide tablets are a Restricted Materials Pesticide requiring a permit from the County Agricultural Commissioner. A training certificate from the manufacturer or distributor often is required before the permit is issued.

Voles (Clethrionomys spp., Phenacomys spp., Microtus spp., Lemmiscus spp.)

There are 10 recognized species representing 4 genera of "voles" in California. The 5 species affecting regeneration efforts are all members of the *Microtus* genus and are found regionally throughout the timber growing regions of California.

Voles are stubby bodied mice with tails shorter than their head and body. They have small, rounded ears, live in burrows (fossorial) but all their forage activities take place on the surface. Unlike pocket gophers, vole burrow entrances are never closed and several burrow openings are often found near each other. Burrow openings are about the size of a golf ball.

Reproduction and Life Traits: Voles, differ from pocket gophers in that they are highly social animals comfortably sharing space with their own kind. Nests are constructed of grasses below ground with breeding generally occurring in spring months between April and May, although the breeding seasons of some southern populations extends into the summer months. Litter sizes average 4-5 young and some populations can have multiple litters in a year. Gestation is generally about 21 days. Females can reach sexual maturity in 30 days. Densities can achieve extremely high numbers in optimal habitats. Voles are crepuscular, meaning their daily rhythms are tied closely with dawn and dusk. Populations usually begin to increase with the first rains in autumn, peaking in the spring when grass growth is greatest. Voles do not hibernate.

Symptoms, Signs and Significance of Damage: Voles generally prefer grassy habitats. Grass management is a key component in addressing vole population fluctuations. Seedlings planted in heavy grass cover in the presence of voles are at risk of feeding to the lower trunks where the damage often goes undetected until the seedling begins to fail (fig. 11.45). Field grown seedlings in the absence of grass control are at risk of being heavily impacted by voles (fig. 11.46), often resulting in a major crop loss. If damage occurs in the winter the signs can go unnoticed until the plants are lifted.

Figure 11.45 Vole damage on coast redwood.

Figure 11.46 Redwood mortality from vole damage.

Management Options: Grass and other herbaceous management around seedlings is key to monitoring and evaluating vole damage. Voles are small, secretive animals susceptible to predation from birds of prey, foxes, mustelids and coyotes. They are not comfortable feeding in an exposed area. Creating a weed-free zone around a seedling is an important consideration when trying to minimize feeding damage.

Trapping: is a useful method of determining vole presence and abundance but may have limited application over a large area. Snap traps can be set (unbaited) perpendicular across the paths leading away from burrow openings. Voles are highly restricted to movements within their pathways and will simply blunder into a set trap.

Toxic baits: are the most often used means of achieving population control. The common toxicant used is Zinc Phosphide applied on a grain bait. Pre-baiting (using an untreated grain bait) is highly effective in preconditioning voles to bait sites. Once the pre-bait has been consumed, replacing it with toxic bait can achieve very high efficacy while minimizing the chance of non-target impacts by limiting the time toxic bait is exposed to the environment.

Exclusion: Vexar™ tubes and TreeShelters™ are effective deterrents in field applications. To improve effectiveness of the tubes they must be positioned tightly to the ground to prevent voles from going underneath and reaching the seedling.

Predator attraction can be achieved by leaving or providing structure adjacent to the planting site. Trees, artificial perches and snags can provide sites from which birds of prey can hunt for voles. However, once a predator captures and consumes a vole its dietary requirements will be addressed for some time until the animal needs to hunt again. Though predators will eat voles, they most likely will not achieve economic control without the aid of other management options.

Rabbits and Hares

Rabbits and hares are members of the Order Lagomorpha distinguished from rodents by having a double set of front incisor teeth, one behind the front. Rabbits are burrowing animals, born in an altricial state (helpless at birth, fully dependent on the mother, much like puppies and kittens). Hares do not use burrows, are born above ground in a precocious state (eyes open) able to leave the nest within days of being born.

There are eight species of Lagomorphs found in California. The Pika (*Ochotona princeps*) is not discussed in this chapter. There are four species of true rabbits, often called cottontails (*Brachylagus* sp., and *Sylvilagus* spp.), and three species of hares (*Lepus* spp., Snowshoe hare (*L. americanus*), White-tailed jackrabbit (*L. townsendii*), and Black-tailed jackrabbit (*L. californicus*).

True rabbits are not often associated with extensive damage in forestry restoration as they are closely associated with briar patches and other heavy cover, never straying far from cover. Hares on the other hand are very mobile and wide ranging.

Reproduction and Life Traits: Female hares can have up to four litters per year with two to eight young per litter under optimal habitat conditions. Daily movements up to 2 miles are common when food and shelter resources are separated. Rabbits and hares are active day and night, though true rabbits tend to be crepuscular, and neither rabbits nor hares hibernate.

Symptoms, Signs and Significance of Damage: Foliage and twigs of seedlings and young trees are eaten (fig. 11.47). Rabbit feeding can be distinguished from deer browsing as rabbits turn their heads when biting a seedling leaving a distinctive 45° angle clean cut. Bark can be stripped from seedlings and shoots and stems. Hares can have severe impacts to young plantations and seedlings. Small trees can be completely consumed and stripped bark often leads to the death of the seedling.

Figure 11.47 Rabbit damage.

Legal Status: Rabbits and snowshoe hares are considered small game mammals in California with a set season and bag limits requiring a hunting license to legally take rabbits. Jackrabbits may be taken all year and there is no daily bag limit.

Management Options:

Exclusion: Vexar™ tubes and TreeShelters™ are effective deterrents in field applications. To improve effectiveness, tubes must be positioned tightly to the ground and checked regularly to insure proper positioning.

Shooting and Hunting: This method may have applications in forestry settings and can control localized populations. Hunting regulations must be consulted when using this method for rabbits.

Repellents: A number of commercially available chemical repellents are available, but little efficacy data exists for forestry applications.

Toxic baits: There are no toxic baits currently registered in California for use on rabbits or hares.

Porcupine (Erethizon dorsatum)

The porcupine (fig. 11.48), like the beaver, is a large rodent. Once abundant, their numbers have plummeted in the state over the past 30 years for unknown reasons. Its historical range included all the Sierra-Nevada, the Cascade Range and much of the Coast Range. Recent studies have shown that it is now uncommon at elevations below 6,000'. The porcupine is arguably one of the most recognizable animals in the forest.

Figure 11.48 Porcupine.

Reproduction and Life Traits: Porcupines den in caves, crevices in rocks, cliffs, hollow logs, snags, and burrows of other animals. They are primarily nocturnal but can be seen in daylight. They are active all year and do not hibernate. When ambient temperatures become very cold (below 9°F), they become lethargic and limit their activity to a single tree. They mate in fall or winter with a gestation of seven months. The usual litter size is one, rarely two. Females are attentive and juvenile mortality is considered low. Porcupines have been documented to live up to 10 years.

Symptoms, Signs and Significance of Damage: Pole-size timber is at the greatest risk from porcupine feeding damage (fig. 11.49). Pines (Ponderosa and Jeffrey) are preferred species, but they will feed on aspen, cottonwood and willow. They will feed on herbaceous plants, inner bark, twigs and leaves of host plants. Tooth marks often indicate porcupine feeding, and bark and wood chips can often be found at the base of a tree being fed upon by porcupines. The tops of pines are often killed, especially in winter months when an animal may limit its movements to a single tree or cluster of trees. Porcupine damage in young, open stands and plantations can be significant if left unchecked. Top-killed trees result in abnormal growth patterns affecting timber values.

Figure 11.49 Porcupine damage.

Management Options: Historic methods of using above ground, strychnine-laced salt blocks to reduce porcupine populations is no longer legal. Use of toxicants requires consultation with the local Agricultural Commissioner or the USDA Wildlife Services prior to use.

Tracking and shooting: During winter months when snow is on the ground porcupine tracking is an effective, albeit time consuming, method of finding individual animals roosting in trees. Where legal, shooting is one method of population reduction.

Exclusion: Porcupines do not jump from tree-to-tree like squirrels. Trunk guards and wraps are effective in limiting the ability of porcupines to climb trees.

Predation: Porcupines are susceptible to predation from mountain lions, bobcats and fishers. Fishers, in particular, are adept at preying on porcupines and have been shown to reduce populations in some areas.

Ground Squirrels

There are *at least* 23 species of ground squirrels in California. These include marmots, ground squirrels (California, Belding, antelope, and golden-mantle), and chipmunks. Fortunately, only a few species can be a problem in reforestation efforts.

Reproduction and Life Traits: Ground squirrels (fig. 11.50) are diurnal, social animals often living near their cohorts sharing burrows and food resources. All ground squirrels hibernate. This means that they are in their burrows during winter months and population surveys can easily under-estimate numbers. Burrows are obstructed (plugged) below ground when the animals are hibernating and are difficult to control during this time.

Figure 11.50 Ground squirrel.

Following hibernation, ground squirrels emerge from their burrows and establish and defend breeding territories. It is during this time that they are most active and visible to help determine population distributions and densities. Young are born and tended below ground in a nursey chamber of the burrow. Litter sizes can vary between 5-8 young, with young emerging from the burrow at about six weeks of age. By six months of age, young resemble the adults.

Symptoms, Signs and Significance of Damage: Damage by ground squirrels was a problem when reforestation used aerial seeding, as the conifer seeds where readily eaten by squirrels and other rodents. With the shift to planting seedlings for reforestation, damage by ground squirrels is limited to a few species. These include:

- California ground squirrel (*Otospermophilus beecheyi*);
- golden-mantled ground squirrel (*Callospermophilus lateralis*); and
- Belding's ground squirrel (*Urocitellus beldingi*) with the golden-mantle considered the most potentially destructive to conifer seedlings.

Damage is non-descript and variable with newly planted seedlings being most at risk from direct feeding (clipping) to the terminal or lateral roots, or from complete loss of the seedling. Some forest managers have observed that the seedling planting soil matrix can attract feeding by golden-mantle squirrels. It therefore may be worth investigating this with the nursery of origin.

Golden-mantle squirrels generally benefit from moderate timber harvesting that opens the canopy and allows greater production of food. Seedlings would be considered another food source in such a scenario.

Management Options: Since ground squirrels hibernate, all management options attempting population control must be during times of activity (March – September).

Exclusion: Vexar™ tubes and TreeShelters™ are effective deterrents in field applications. To improve effectiveness tubes must be positioned tightly to the ground and checked regularly to insure proper positioning.

Trapping: Snap traps and Conibear Model 110 (for the larger California ground squirrel) traps can be effective in controlling ground squirrels. Traps need to be set during daylight hours, leaving traps after dark increases capturing non-target predatory species.

Toxic baits: The common toxicant used is Diphacinone applied on a grain bait. Pre-baiting (using an untreated grain bait) is highly effective in preconditioning ground squirrels to bait sites. Once the pre-bait has been consumed, replacing it with toxic bait can achieve very high efficacy while minimizing the chance of non-target impacts by limiting the time toxic bait is exposed to the environment. Using home-made or commercially available bait stations is an effective way of minimizing exposure to non-target species. Baits are best accepted by ground squirrels late in the summer when their dietary focus shifts to seeds.

Fumigants: can be effective if used properly. Soils need to contain some moisture to minimize venting of fumigant gases through soil pores; since ground squirrels hibernate, fumigants are only effective after the animals awake from hibernation. Several types of fumigants are available:

- Incendiary devices (smoke bombs, flares) often release sulfur gas, asphyxiating animals below ground. Caution needs to be exercised during dry months when grasses may ignite.
- Carbon Monoxide gas has been legal to control fossorial (below ground) pests since 2012. Both commercial and self-designed devices have been developed to deliver CO gas to burrows.
- Aluminum Phosphide tablets are a Restricted Materials Pesticide requiring a permit from the County Agricultural Commissioner. A training certificate from the manufacturer or distributor is often required before the permit is issued.

Shooting: Where safe, shooting can eliminate a small number of animals. It is often time consuming and efficacy is dependent on the skill of the marksman.

Tree Squirrels (Sciurus, Tamiasciurus, and Glaucomys)

The western gray squirrel (*S. griseus*), the Douglas squirrel (chickaree) (*T. douglassii*) and the northern flying squirrel (*G. sabrinus*) are the three native species of tree squirrels found in California's forests. Of these, the western gray and Douglas squirrels can damage conifers.

Reproduction and Life Traits: Tree squirrels are diurnal (except for the flying squirrel which is nocturnal). Tree squirrels **do not** hibernate and remain active throughout the year. Whereas ground squirrels will climb trees, tree squirrels **never** go below ground. Tree squirrels are primarily herbivorous, feeding on conifers, seeds and fruits, and fungi. They will cache food for eating during winter months. They forage in trees or on the forest floor. Tree squirrels nest in abandoned woodpecker cavities, snag cavities or make a nest of branches lined with bark, grass, lichens and moss. Young are born between March and June, with one litter of 3-5 per year.

Symptoms, Signs and Significance of Damage: Tree squirrel feeding and associated damage is most often near the top of pole and saw-log sized trees. Douglas squirrel feeding in seed orchards can be a problem if feeding is heavy and the seed cones are eaten. In winter months, tree squirrels often feed on and remove the tips of lateral branches. Generally, this is not considered a long-term impact to the tree and is not considered a negative impact to reforestation efforts.

Tree squirrels have been known to kill the tops of pines and coast redwoods. This feeding behavior often happens in the spring when sap flow is high. Bark is removed and feeding impacts the cambium. It's not clear if bark is also removed for nest building during this time. Impacted trees are not killed, but the damage can affect log quality and can lead to secondary pest problems (pine). The economic impacts from squirrel damage are not well documented in California as the damage is often localized and transient.

Legal Status: Tree squirrels are considered small game mammals in California with a set season and bag limits requiring a hunting license to legally take them. California Fish and Wildlife regulations should be consulted prior to taking tree squirrels.

Management options: Given their legal status few management options are available in forestry to control squirrel populations:

Toxicants – None are registered

Fumigants – None are registered

Trapping – Live or kill trapping is not allowed under California law.

Shooting – Under appropriate hunting statutes tree squirrels may be legally taken by shooting during the defined hunting season.

Silvicultural options – younger stands are at greatest risk from squirrel damage. If damage is occurring and limiting regeneration efforts, concentrating control measures in these stands may lessen the threat.

Woodrats (Neotoma fuscipes)

Of the three species of woodrats found in California, only the dusky-footed woodrat may be of concern to coastal forest managers. Found primarily in the coast redwood – Douglas-fir belt of coastal California and foothills of the Sierra Nevada, the species has been known to damage regeneration efforts in coast redwood stands. They are mostly nocturnal.

Reproduction and Life Traits: Woodrats feed on woody plants, fungi, flowers, grasses and acorns. They prefer moderate canopy cover and are often abundant in chaparral habitats. Nests are constructed of sticks in or at the base of a tree. Woodrats breed from December to September with peak breeding in the spring. Woodrat populations have been shown to be highest in coastal redwood stands between 15-30 years old. They are considered a primary prey species for northern spotted owls (*Strix occidentalis)* in coast redwood forests.

Symptoms, Signs and Significance of Damage: Woodrat feeding damage is often seen within the clumps of sprouting coast redwoods (fig. 11.51) or on the terminal leader of redwood saplings. They have been known to remove the outer bark for nest material without exposing or removing the sapwood. Damage within stands is often sporadic and unpredictable. Stands become less attractive, and consequently less populated by woodrats after 30 years.

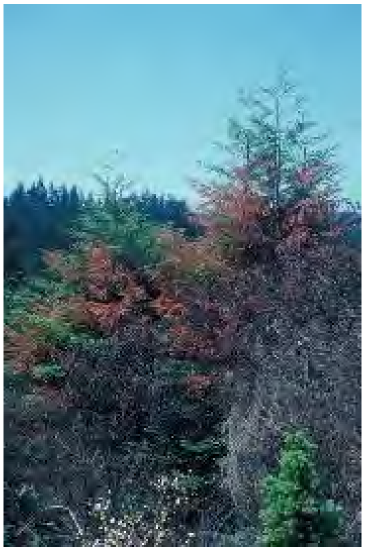


Figure 11.51 Woodrat damage to a clump of redwoods.

Management options:

Toxicants – Given the importance as prey for spotted owls, consult the local Agricultural Commissioner prior to any use of toxic baits.

Fumigants – None are registered

Trapping – The use of snap traps may be effective at a single sight, but is not generally considered effective in a larger forestry context.

Shooting – Given that woodrats are nocturnal, shooting is not considered an effective control method.

Silvicultural options – younger stands are at greatest risk from woodrat damage. If damage is beyond economic thresholds re-examining silvicultural practices may be the best option.

Mountain Beavers (Aplodontia rufa)

Mountain beavers (fig. 11.52), AKA "mountain boomers", and "sewellel beaver", "ground bear", and "giant mole" are considered the oldest type of rodent in North America. Found throughout the Cascades, Klamath and Sierra Nevada ranges and sporadically along the coast range. They are often found near water and need soft, friable soils to construct underground burrows. They will feed on thimbleberry, salmonberry, lupines, willows, ferns and young conifers. They will cache food in their burrows.

Figure 11.52 Mountain beaver.

Some populations of mountain beavers are afforded special protections in California. Consult with the local Agricultural Commissioner prior to initiating any management measures with this species.

Reproduction and Life Traits: Mountain beavers do not concentrate their urine and require large daily intakes of water. They do not hibernate and are active throughout the year. They are non-migratory and sedentary. They will defend their burrows but territories will overlap and most activity occurs relatively close to the burrow. Mountain beavers breed from December through March with the peak in February. Litter size varies between 2-3 young with females not reproductively active until their second year.

Symptoms, Signs and Significance of Damage: Mountain beavers are known to damage young seedlings. Damage can be heavy and severe in Douglas-fir plantations where mountain beavers will select lateral and terminal branches on the seedlings, saplings and pole trees. Lateral and terminal branches have been damaged up to 10'. Basal girdling and under-mining of tree roots from burrowing can occur in young stands.

Management options:

Exclusion: Vexar™ tubes and TreeShelters™ are effective deterrents in field applications. To improve effectiveness of the tubes they must be positioned tightly to the ground to prevent mountain beavers from digging below or climbing over and feeding on the tree. Depending on the size of the seedling being impacted, tubes up to 30" may need to be considered.

Trapping: Conibear Model 110 traps set (un-baited) in the entrance of the burrow can be used to catch mountain beavers.

Toxic baits: Consult with your Local Agricultural Commissioner to determine if this is a legal management option.

Fumigants: Consult with your Local Agricultural Commissioner to determine if this is a legal management option. Fumigants can be effective if used properly. Soils need to contain some moisture to minimize venting of fumigant gases through soil pores; since mountain beavers do not hibernate, fumigants may prove useful throughout the year if soil conditions are right. Several types of fumigants are available:

- Incendiary devices (smoke bombs, flares) often release sulfur gas, asphyxiating an animal below ground. Caution needs to be exercised during dry months when grasses may ignite.
- Carbon Monoxide gas has been legal to control fossorial (below ground) pests since 2012. Both commercial and self-designed devices have been developed to deliver CO gas to burrows.
- Aluminum Phosphide tablets are a Restricted Materials Pesticide requiring a permit from the County Agricultural Commissioner. A training certificate from the manufacturer or distributor often is required before the permit is issued.

Ungulates (deer, elk, livestock)

A variety of wild and domesticated ungulates are found throughout the forests of California. Most are sedentary and non-migratory (except for some eastern mule deer populations) and can have repetitive impacts on forest regeneration efforts. Domestic species include cattle, horses, sheep and goats, while wild ungulates in a forest setting are restricted to deer and elk. Cattle, elk and horses are grazers while deer, sheep and goats tend to be more omnivorous browsers. Deer and elk population densities are set by the carrying capacity of the habitat and are present throughout the year; while livestock densities can be arbitrary and seasonal.

Legal Status: Deer and elk are game species with strict harvesting restrictions. Depredation permits can only be authorized by the California Department of Fish and Wildlife. Livestock are private property under the control of the owner.

Symptoms, Signs and Significance of Damage: Ungulates are big animals that can eat up to 3% of their body weight in a day. Damage can be from direct feeding to lateral and terminal buds, rubbing from antlers (fig. 11.53) or other body parts (cattle), or trampling. Deer can reach terminal branches up to 5', while elk can reach even higher; horses and goats can remove bark from trunks. Damage can be localized and severe depending on density and duration of the grazing or browsing pressure.

Figure 11.53 Deer antler rub damage.

Management options:

Exclusion: Vexar™ tubes and TreeShelters™ are effective deterrents in some field applications. Depending on the size of the seedling being impacted, tubes up to 30" may need to be considered. Tubes may be useful for deer and smaller ungulates, but are not considered effective for larger animals such as elk, cattle or horses. Fencing may be needed to exclude larger animals for a period of time until the regeneration effort grows beyond their reach.

Repellants: though commercial repellants are available, their utility in forestry operations is limited by the need for constant application. Some products are packaged in small bags or pouches to hang on the tree, but their effectiveness has not been substantiated in the scientific literature.

Behavior modification: Livestock can be conditioned to avoid sensitive areas by placing salt blocks, mineral supplements, and water sources away from the area needing protection. Placing "rubbing posts" away from planted areas can condition livestock to seek out alternative sites for scratching and rubbing.

Bears (Ursus amercicanus)

The American black bear is widely distributed in forested regions throughout the state and is the only species of bear found in California. Though the name implies a single-color variation, the "black" bear can be black, brown or "cinnamon" in color.

Reproduction and Life Traits: Black bears are omnivorous. They will readily feed on grasses, forbs, fruit, nuts, carrion and will prey on living animals. They tend to be seasonal specialists feeding on grasses, forbs, and insects during the spring, berries in the summer and acorns and fish carrion in the fall. They have been known to kill adult deer, and livestock. Young are born in winter dens in January and February. Young will stay with the female for at least 1.5 years, with individuals living up to 25 years in the wild.

Legal Status: Black bears are game species with strict harvesting restrictions. Depredation permits can only be authorized by the California Department of Fish and Wildlife.

Symptoms, Signs and Significance of Damage: Bear damage usually occurs during the later spring months prior to the emergence of summer fruits. This is a time of year when bears are losing weight and lactating females are under stress caring for their young. Bear feeding removes the bark of coast redwoods (fig. 11.54), Douglas-fir and Port-Orford cedar, exposing the cambium which is scraped with the canine teeth. Damage is often associated with roads, but damaged trees can be found randomly in a stand. Feeding is initiated by increased spring sap flows and is often associated with pre-commercial thinning (PCT) activities which further increases sap flows. Feeding is often initiated by females in search of food to meet their lactating energy demands, thereby exposing her young to the behavior. Trees are often "tested" and not fed upon, only to be revisited later in the season when resin flows have increased. Damage can be localized, sporadic, minor or severe. Stands experiencing bear feeding damage often share similar characteristics. Cohorts are often even-aged stands, between12-20" dbh (fig. 11.55), have been pre-commercially thinned, and have good road access.

Figure 11.54 Bear damage.

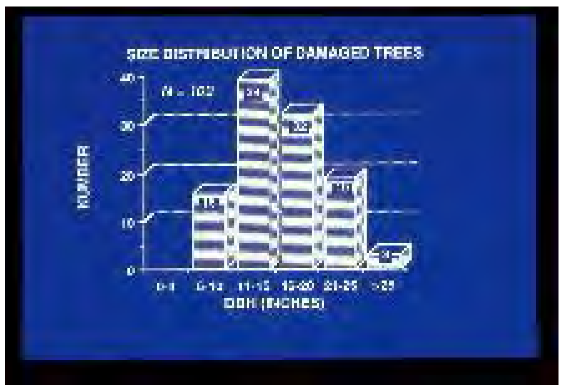


Figure 11.55 Amount of bear damage varies by tree diameter.

Management options:

Silvicultural practices: Long-term transition to alternative silvicultural treatments, even-aged to uneven-aged, may make stands less attractive by abandoning the need for PCT. Though anecdotal evidence suggest that stands above 160 ft^2 basal area may be less susceptible to bear feeding, that has not been validated through long-term studies.

Hunting: Areas targeted for recreational hunting can reduce bear numbers during the authorized hunting season.

Alternative foods: Though not currently allowed in California, research in Washington State has demonstrated some success using alternative food sources (sugar-wood pellets) during the time of year when bear damage is predicted to occur.

Abiotic Damage

Abiotic damage is caused by non-living, non-infectious agents that physiologically or physically impact a plant. Abiotic damage can result from a broad range of interacting host and environmental conditions, either natural or human-induced, that are often only partially understood. Weather events and climatic conditions (e.g. hail, frost, drought) produce the most common abiotic damage seen in forest plantations. In situations where best management practices are followed, extreme or uncommon conditions are typically needed to produce damage. Extreme is a relative term because it depends on what is extreme for a given site, time of year, tree species, or genetic stock. It may relate to abnormal highs or lows, how quickly conditions change from one to the other, how long adverse conditions persist, or the influence of coincidental factors.

Diagnosis of abiotic damage is complex and may require making some subjective determinations with respect to changes in the environment and their possible effects. Confirmation of certain abiotic damage (i.e., road salt and mineral deficiencies) may require laboratory analysis. An excellent resource for identifying abiotic damage is the USDA Forest Service Agricultural Handbook No. 521, Diseases of Pacific Coast Conifers, available on-line. The possible permutations of abiotic damage mean that not every situation will fit a text book description. Often the event or condition that produced damage is not directly observed and it may be necessary to review records of past events to identify likely causes. Conversely, cause and effect may be relatively simple to deduce, such as with the pattern of wounding that is caused by hail.

An important aspect of diagnosing abiotic damage is recognizing that the damage is not caused by a biotic agent. In general, damage caused by abiotic factors tends to be more uniform, non-specific and widespread. For example, damage caused by freezing temperatures can affect multiple tree species in a similar way across an elevational band or geographic feature. Note that symptoms of biotic and abiotic damage can overlap, and secondary organisms can enter damaged tissue. It is useful to learn the signs and symptoms of the most common and significant causes of biotic damage so that these can be looked for. Confirming their absence is a strong case for abiotic damage. When secondary organisms invade damaged trees, their presence is often inconsistent. Sometimes they are present, other times not, or different organisms may be present on different trees.

In many situations, abiotic damage is the result of an unusual event with a low probability of reoccurrence. It may be a learning experience that influences future management decisions, but otherwise cannot be mitigated directly.

Drought

Drought is a reoccurring feature of California's Mediterranean Climate that impacts conifers of all types and ages. The extent of damage depends on the severity and length of drought. Impacts can be particularly severe on young trees, which have less well developed root systems. Damage often is concentrated in drier locations, but is also influenced by host genetics, microsite (e.g. local areas of shallow soil), or even planting irregularities. Reduced moisture availability also increases the susceptibility of trees to insects and diseases. Damage and mortality of drought-stressed trees is often attributed to insect pests, but with the youngest trees the role of insects may be minimal compared to the direct effects of drought. Stocking control and control of vegetation that competes with young conifers for water is the single most important action that can be taken to improve tree survival.

Drought also suppresses growth. Visible manifestations are reduced height and shoot growth, shorter than normal needles, and if several years of needles are present, the premature loss of older needles (fig. 11.56). The crowns of chronically stressed trees develop a characteristic thin appearance due to poor growth and needle retention. Severe or chronic drought may also lead to shoot and top dieback.

Figure 11.56 Premature shedding of older needles on incense cedar due to drought stress.

Drought can interact with other factors to produce increased levels of damage. In spring of 2003, young incense cedar exhibited dieback and mortality over a large area of northern California and southern Oregon. The damage was speculated to be the result of both drought and a sudden shift to unusually low temperatures in late October of 2002. The classic example of increased damage occurs when drought-stressed conifers are killed by bark beetles such as the western pine beetle, Ips species, and fir engravers (see insect section).

Hail

Foliage and smaller diameter stems are directly injured by the impact of hail. Young tissue is particularly susceptible. Damage occurs on many different plant species, but can vary significantly by species. Douglas-fir is more susceptible than other conifers. Look for scattered spots of tissue bruising or wounding on the upper sides of foliage and branches (fig. 11.57). Damage can be heaviest on one side of the crown and main stem depending on the direction and intensity of wind-driven hail. Needles may be lost. With heavy damage, spots of injury will coalesce and shoots and tops may be weakened or killed (fig. 11.58). Crown dieback can affect tree growth for many years after injury. Lighter damage may not immediately be apparent, but become more obvious as tissue dies and calluses.

Figure 11.57 Partially healed wounds from hail damage on sugar pine.

Figure 11.58 Dieback in the crown of a sugar pine damaged by hail.

Frost

Damage from frost is most likely in the spring. It occurs when new tissues are exposed to unusually late below-freezing temperatures. Damage can vary from one tree to the next based on species, how much new growth is exposed, and position on the landscape. Damage often is restricted to cold air sinks or “frost pockets.” Classic spring frost damage kills most new growth on a young tree (fig 11.59). Larger trees respond with additional new growth and recover well, while seedlings and small trees are at risk of significant dieback and mortality because of their small size and higher ratio of new to old growth. Although less common, damage can also occur in the fall when the current year’s growth has not yet been conditioned to the coming cold season.

Figure 11.59 New shoots and needles of Douglas-fir damaged by spring frost.

Prevention is the best means of avoiding frost damage. When establishing a plantation, it is important to recognize frost pockets and avoid planting trees unlikely to survive there. Douglas-fir planted on the eastern edge of its range in the Cascade Mountains of northern California has suffered frost damage in these situations. Utilize planting stock from the appropriate seed zone.

Winter Needle and Shoot Desiccation

This type of injury can be caused by a variety of winter conditions that promote the drying of foliage and sometimes stems, with inadequate uptake of moisture by the roots to replace what is lost. A common form of this damage is referred to as "red belt" because it occurs in a distinct band or belt on the landscape that follows an elevation contour. It occurs when a temperature inversion causes affected trees to be exposed to warm daytime air while the soil is too cold for water uptake. Another situation that can lead to desiccation is a low or non-existent mid-winter snow pack, due to drought, at elevations were young trees would normally be covered by snow. Foliage is exposed to sun and wind while roots and soil remain cold.

Milder cases of desiccation result in needles browning from the tip downward (fig 11.61). Once new growth begins in the spring, older, damaged needles are retained or lost, depending upon the amount of necrosis (browning). If needles dry completely, shoot tips may also be impacted. Mild desiccation is primarily cosmetic. Trees with partially brown, desiccated needles can appear dead (fig. 11.60), but closer inspection of foliage and shoots should reveal that they are still alive. Such trees "green up" when new growth begins in the spring. However, severe desiccation of young trees can cause dieback and mortality.

Figure 11.60 Ponderosa pine with winter needle desiccation commonly referred to as red belt.

Herbicide Damage

Best management practices for herbicide use are covered extensively in this manual. Following these practices provides insurance against damage from herbicides, but not a guarantee. Damage may be due to an error made during herbicide application or perhaps some unrecognized host or environmental condition. Symptoms of herbicide damage vary with the type and amount of herbicide used and include distortion and dieback of shoots, and twisting, stunting, discoloration, desiccation, and loss of needles. Diagnosis is usually based on three conditions - symptoms, no evidence of other causes, and a recent history of herbicide application.

Other Abiotic Damage

The possible causes of abiotic damage are wide-ranging. Additional causes include solar radiation, soil mineral imbalances, road salt, pollution, fire, excess water, and various types of mechanical damage.

Additional Resources

More is being learned about pest organisms and their ecological roles all the time, which in turn influences how land managers respond to their damage. Invasive pests are significantly impacting certain conifer species and the threat of new invasive pests is ever present. Climate change is also producing new impacts. Consequently, the pests and abiotic factors considered important are expected to change over time.

The California Forest Pest Council offers education on forest pests through its annual meeting, various field meetings, and targeted training sessions. The University of California, CAL FIRE, and the USDA Forest Service also provide a variety of educational services, and assistance from technical experts who are located throughout the state.

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References

Alfaro, R. I., and S. G. Glover, editors. 1989. Insects affecting reforestation: biology and damage. Proceedings of a meeting of the IUFRO working group on Insects Affecting Reforestation, Vancouver, British Columbia, July 3-9, 1988. Forestry Canada, Pacific and Yukon Region, Pacific Forestry Centre.

Austin, L., and J. S. Yuill. 1945. Use of shoot characters in selecting ponderosa pines resistant to resin midge. Ecology 26:288-296.

California Forest Health Specialists. 2016. California forest insect and disease training manual. USDA Forest Service Region 5 and California Department of Forestry and Fire Protection. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev3_046410.pdf.

Cram, M. M., M. S. Frank, and K. M. Mallams, technical coordinators. 2012. Forest nursery pests. USDA Forest Service Agricultural Handbook 680.

Daterman, G., A. Eglitis, D. Czokajlo, Ch. Sack, and P. Kirsch. 2001. Attract and kill technology for management of European pine shoot moth (*Rhyacionia buoliana)* and western pine shoot borer (*Eucosma sonomana)*. Journal of Forest Science 47 (special issue 2):66-69.

Eaton, C. B., and J. S. Yuill. 1971. Gouty pitch midge. USDA Forest Service Forest Pest Leaflet 46.

Ferrell, G. T., W. D. Bedard, and J. L. Jenkinson. 1987. Gouty pitch midge damage to ponderosa pines planted on fertile and infertile soils in the western Sierra Nevada. USDA Forest Service Pacific Southwest Forest and Range Experiment Station Research Note PSW-390.

Furniss, R. L., and V. M. Carolin. 1977. Western forest insects. USDA Forest Service Miscellaneous Publication 1339.

Geils, B. W., J. C. Tovar, and B, Moody. 2002. Mistletoes of North American conifers. USDA Forest Service General Technical Report RMRS-GTR-98.

Gillette, N. E., J. D. Stein, D. R. Owen, J. N. Webster, and S. R. Mori. 2006. Pheromone-based disruption of *Eucosma sonomana* and *Ryacionia zozana* (Lepidoptera: Tortricidae) using aerially applied microencapsulated pheromone. Canadian Journal of Forest Research 36:361-368.

Hawksworth, F. G., and D. Wiens. 1996. Dwarf mistletoes: biology, pathology, and systematics. USDA Forest Service Agricultural Handbook 709.

Hessburg, P. F., D. J. Goheen, and R. V. Bega. 1995. Black stain root disease of conifers. USDA Forest Service Forest Insect and Disease Leaflet 145.

Kinloch, B. B., Jr., M. Marosy, and M. E. Huddleston, editors. 1996. Sugar pine: status, values, and roles in ecosystems: proceedings of a symposium presented by the California Sugar Pine Management Committee. University of California Division of Agriculture and Natural Resources Publication 3362.

Mitchell, R. G., and L. L. Sower. 1988. Phenology and heat accumulation as field guides for the seasonal history of the western pine shoot borer (Lepidoptera: Olethreutidae). Journal of Economic Entomology 81:286-289.

Niwa, C. G., L. L. Sower, and G. E. Daterman. 1987. Chemistry and field evaluation of the sex pheromone of ponderosa pine tip moth, *Rhyacionia zozana* (Lepidoptera: Tortricidae). Environmental Entomology 16:1287-1290.

Otrosina, W. J., and R. F. Scharpf, technical coordinators. 1989. Proceedings of the symposium on research and management of annosus root disease (*Heterobasidion annosum)* in western North America. USDA Forest Service General Technical Report PSW-116.

Otrosina, W.J.; Kliejunas, J.T.; Smith, S.; Cluck, D.R.; Sung, S.S.; Cook, C.D. 2007. Black stain root disease studies on ponderosa pine parameters and disturbance treatments affecting infection and mortality. Acta Silva. Lign. Hung., Spec. Edition: 247-251.

Scharpf, R. F., technical coordinator. 1993. Diseases of Pacific Coast conifers. USDA Forest Service Agricultural Handbook 521.

Sower, L. L., and R. G. Mitchell. 1987. Host-tree selection by western pine shoot borer (Lepidoptera: Olethreutidae) in ponderosa pine plantations. Environmental Entomology 16:1145-1147.

Stevens, R. E. 1959. Biology and control of the pine needle-sheath miner, *Zelleria haimbachi* Busck (Lepidoptera; Hyponomeutidae). USDA Forest Service Pacific Southwest Forest and Range Experiment Station Technical Paper 30.

Stevens, R. E. 1971. Pine needle-sheath miner. USDA Forest Service Forest Pest Leaflet 65.

Stevens, R. E. 1971. Ponderosa pine tip moth. USDA Forest Service Forest Pest Leaflet 103.

Schmitt, C. L., J. R. Parmeter, and J. T. Kliejunas. 2000. Annosus root disease of western conifers. USDA Forest Service Forest Insect and Disease Leaflet 172.

USDA Forest Service, Region 5. 2007. Managing for Healthy Port-Orford-cedar in the Pacific Southwest Region. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5332563.pdf.

USDA Forest Service. 2012. Forest Nursery Pests. Agriculture Handbook 680.
https://www.fs.fed.us/sites/default/files/legacy_files/Forest%20Nursery%20Pests-web.pdf

Wood, D. L., T. W. Koerber, R. F. Scharpf, and A. J. Storer. 2003. Pests of the native California conifers. University of California Press Natural History Guide 70.

Chapter 12:
Reforestation of Areas Burned by Large Wildfires

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Introduction

California's forests with a Mediterranean climate have a long history of frequent fires (J. D. Miller & Safford, 2017), and the frequency and severity of fires across the West are increasing (Dennison, Brewer, Arnold, & Moritz, 2014; Stephens et al., 2018). The frequency of these fires have increased across all land ownerships, most dramatically on federal forest lands (Starrs, Butsic, Stephens, & Stewart, 2018). Fires that exceed 10,000 acres are becoming more common in the west and in particular in the forested portion of California (Stevens, Collins, Miller, North, & Stephens, 2017). Very poor natural regeneration after fires is common as a recent survey of fires on 10 National Forests in California found that 43% of all plots within fire perimeters had no conifer regeneration (Welch, Safford, & Young, 2016). These mega-fires are the result of more than a century of fire suppression, subsequent overstocked forests, drought, insect damage and a warming climate. Salvage logging after wildfire is a common practice on many managed forest areas and the effects are often closely related to site-specific characteristics (Leverkus et al., 2018; McIver & Starr, 2000). For forest land owners that precede with salvage logging to recoup value and initiate successful reforestation, there are significant challenges to ensure low post fire soil erosion, successful conifer reforestation, and the maintenance of other desired habitat and environmental outcomes. Fires of this magnitude pose unique challenges for those responsible for the subsequent timber salvage and reforestation operations. Those challenges include timely landscape level planning with complex decisions on logistics; and potentially limited labor resources and/or budget. This chapter will focus on the planning and practices that will help make these projects a success with a little less stress.

Planning

Planning the reforestation of a large wildfire requires a cooperative effort with those that are planning and executing the timber salvage operation as timing and location of reforestation activities are heavily dependent on salvage strategies. If the post-fire salvage requires multiple years or is more than several thousand acres, the reforestation effort will need to be broken up into multiple years. Using a fire that burned 12,000 acres in August of 2017 as an example, and on which salvage operations begin immediately, the beginning of the planting effort would likely be planned for fall of 2018 or spring of 2019. This would allow enough acreage to have salvaged completed and subsequent site preparation treatments in place. It is reasonable to split the effort into equal pieces, the size of which would reflect landowner objectives and capabilities. A common tactic for this is to split the burn area into three project areas of 4,000 acres each. This requires the planting of approximately one million trees per year and corresponding vegetation management treatment activities to ensure establishment of the seedlings. This seems to be a common threshold above which operational restrictions and logistics become increasingly more difficult.

The number of acres chosen as a yearly reforestation goal is up to the reforestation team and its capacity to carry out the necessary steps to properly establish the new forest. Some factors that limit the ability to successfully accomplish planting large acreages are lack of a suitable seed source, budget constraints and limited personnel. It is important to make reasonable goals based on the reforestation team's capacity and salvage schedule. Once a reforestation schedule is determined and seeds are sown in the nursery, the project planting area must be prepared the following spring. Vegetation management activities should be closely coordinated to ensure sites planned for planting are completed first. Planning the vegetation management activities should center around, but not be limited to, the area to be planted first.

Unitizing

Immediately after these large fires are controlled or even during suppression activities, foresters will begin making plans for the salvage of the damaged timber. Once the overall planning is completed regarding the integration of fire salvage and what can be a multi-year reforestation effort, the next step will be to break the wildfire area into logical harvest units and mapped... These operational salvage units will concentrate on the logging method most appropriate to the varying terrain and slopes present, as well as the available access. However, while the urgency of beginning the salvage of the fire damaged trees will drive early planning efforts, this is also the time for the reforestation team to become involved. Using the harvest units as a start, the entire fire area can be broken down into ultimate reforestation units as well. This complete unitization of the burn area will be critical to the systematic and orderly restoration effort of the complex project.

Multiple strategies can be utilized, but all depend on common principles. Units should be delineated into a size that is easily manageable, generally less than 100 acres, and that contain similar soils, slope, and timber type. Boundaries with features such as roads, streams or ridgelines can be used to define the unit. Timber salvage methods can further aid in determining unit boundaries as harvest methods should generally not be combined in a single reforestation unit, i.e. helicopter yarding and tractor yarding in one unit. A single logging method will result in common post-harvest conditions that will more easily yield common reforestation techniques.

Post-fire satellite imagery products can help with the unitization process as fire intensity can be variable in all fires, but especially in large ones. Rapid Assessment of Vegetation Condition after wildfire (RAVG) products produced for fires that burn some federal land provide information that can assist post-fire vegetative management planning, and are generated by a change detection process using two satellite images captured before and after a wildfire (J. D. Miller, H. D. Safford, M. Crimmins, A. E. Thode, 2009; J. D. Miller & Quayle, 2015; J. D. Miller & Thode, 2007). The method is sensitive to vegetation mortality from the wildfire event and produces maps with estimates of basal area loss. In wildfires involving thousands of acres, aerial imagery is invaluable to identify unburned islands, non-timbered areas and other features not readily map-able using ground-based observation. Variability in fire severity that leads to different salvage intensity can be identified and delineated for follow-up reforestation as planning intensities may vary In addition, unstable areas or areas with high potential for erosion should be identified in this process because they may need different vegetation management strategies than more stable geological areas. A unique identifier should be assigned to the unit that can serve as a constant ID for the reforestation effort and beyond. Once the unitization process is complete the planning phase of the operation can begin.

Planning the progression of the planting project depends on the progression of the timber salvage operations and subsequent site preparation activities. Units in which the timber salvage has been completed would be the best candidates in which to start the project because the ground disturbing harvest activities following salvage serve to scarify the soil, preparing the soil for planting and often increasing drainage potential. Slash left on the ground after harvesting such as limbs, tree tops and sub-merchantable trees will further serve to stabilize the soil. Where soils are hydrophobic and there is a high likelihood of erosion, areas that were predominantly brush, small trees or young plantations and that don't have merchantable timber should be delayed to allow some re-vegetation. These areas should also be considered for mechanical tilling or sub-soiling since there will be no harvest activities to help mitigate such hydrophobic (e.g. increased water repellency, decreased infiltration, and increased surface runoff) conditions. Prioritizing the planting progression also depends on the plan for mechanical site preparation activities within the burned area and the ability to apply pre-plant herbicides. If landing piles are to be disposed of by a chipping operation or by burning, it is important to have those activities completed prior to planting to avoid damage to the seedlings around the landings.

Large projects will require additional labor sources. It is a good idea to become familiar with the larger forest labor contractors that have the expertise and personnel to tackle the large numbers of trees to be planted and the potentially large acreages that will need to be hand sprayed. It is also important to include helicopter contractors in this phase of the reforestation effort so they can plan ahead for the additional work load.

Sourcing Seed

Seed sources could be limited for landowners faced with large reforestation projects. Outside of seed already owned and stored by the landowner, the best starting point for private landowners to find suitable seed is to consult the Cal Fire forester in the area nearest the burn. The L.A. Moran Reforestation Center in Davis, California maintains the State Seed bank that would be available to the public in time of need. The potential to get seed would be limited by the inventory of the seed in the bank that is appropriate to plant in the zone, elevation and species of the reforestation project. Another possibility for seed is to consult the larger landowners in the area of the burn. Most large timberland owners maintain seed banks to cover their reforestation needs following fire and they may have surplus quantities to sell. Private seed companies such as Silva Seed or Pacific Forest Seed may have a store of seed for sale and in some cases some may have seedlings grown for your area. Federal land managers maintain a seed bank in Placerville, California that may be available in times of need. The reforestation professional should resist the temptation to use readily available, but inappropriate seed and should adhere to existing standards of acceptable seed zone and elevation for the local burn area. If no seed appears to be immediately available, or to prepare for the future, trees within the burned area that are damaged, but survive the burn will frequently have a “stress crop” of cones that would yield seed for reforestation projects. In many cases the stress crops will not produce adequate quantities of viable seed for the total reforestation needs. It is therefore very important to verify that the developing cone crop contains enough viable seed of sufficient quality to make a collection worthwhile. Additionally, reconnaissance of unburned forest stands in the vicinity may yield seed collection opportunities. There are contractors available that specialize in the collection of conifer cones. Consult with the Area State Forester, Cooperative Extension Forester or a local Registered Professional Forester for information about climbing contractors for cone collection. Another consideration for alternate seed sources is to choose seed that is available from similar ecotypes from adjacent seed zone within breeding zones.

Mechanical Site Preparation

If mechanical site prep is an option for the burned area, it is important to make those arrangements well in advance of the planned reforestation project. This is true, not only to ensure contractor availability, but also to take advantage of any opportunity to increase infiltration rates and disturb the potential post-fire hydrophobic soil conditions. This is considered especially important in the first year following the fire and prior to the first heavy rains. Hydrophobic soils are very common in burned areas and particularly where the fire intensity was extreme. Coarse textured soils are particularly prone to the development of a hydrophobic layer.

Piling or windrowing residual slash for subsequent burning has been used in the past to reduce fuel loading and to facilitate planting. The potential fire risk to the plantation from remaining fuels after the fire salvage needs to be carefully balanced with the benefit of having the slash on the ground to mitigate soil erosion. This is particularly true since recent experience has demonstrated that seedlings can be successfully planted through such slash loads without significant survival or growth issues. Other mechanical site preparation methods such as sub-soiling, ripping or tilling can have many beneficial effects in the establishment of new forests after fire. The use of sub-soiling was initially promoted as a mitigation measure for compacted soils in forest regeneration projects, but another positive effect is that it increases the area available for planting by exposing bare soil that may have been obscured by logging debris. It also serves to break down slash by crushing it and incorporating some of it into the soil. Slash that is in contact with the soil breaks down significantly more rapidly through microbial activity than debris that is not in contact with the soil. Starting the slash decomposition process is important not only to hasten the nutritional recycling process, but also because slash remains a source of increased fire hazard until it decomposes. Well planned and executed contour sub-soiling has been demonstrated to be an option in mitigating hydrophobic conditions on some sites in California by increasing the infiltration rate prior to the onset of winter rains and breaking up potential channels that could lead to excessive runoff caused erosion (James & Krumland, 2018). Sub-soiling can also improve the efficacy of soil active herbicides that require application to bare ground. For example, Hexazinone and Oxyflourfen are generally more effective when bare soil is exposed since they are susceptible to being tied up in organic material if high levels of slash obscure the soil layer and reduce the application effectiveness to the target soils.

Vegetation Management

Chapter 8 of this manual addresses the principles of vegetation management in detail. For this chapter we will discuss some of the unique challenges that are associated with vegetation management in the reforestation of areas that have burned.

The regeneration forester/Pest Control Advisor needs to anticipate the rapid vegetation succession that will occur. Burned areas can re-vegetate very rapidly as fire both scarifies serotinous weed species seeds and releases a flush of nitrogen that can be utilized by new plant growth. Taking advantage of a largely intact root system, some brush species and most hardwood tree species will re-sprout in the first year after the fire and grow rapidly. The following spring will see the initial flush of herbaceous weed species as well as the germination of brush seedlings. These two separate components of competing vegetation may have to be treated in different ways and at different times to be successful. The re-sprouting brush and hardwood plants may not have enough leaf area re-established for successful treatment with foliar active herbicides until after a full growing season has passed. Going back to the example of the 2017 August burn, the earliest the brush and hardwoods would be ready for a foliar treatment would be after the full growing season in 2018. In some instances and if using a helicopter application method, it may take even more time to allow the leaf area to grow to treatable levels with foliar active herbicides such as Imazapyr and Glyphosate. On the other hand, in the case of an early season fire the brush species and re-sprouting hardwoods may develop enough leaf area to successfully treat in the same season as the burn. In general, brush and hardwood species that are easily controlled with foliar applied herbicides should be treated as soon after the burn as possible as directed treatments on early stage small re-sprouts require less herbicide volume and are less expensive than treating larger sprouts. Hand-directed treatments may be preferable in this situation because helicopter applications may not provide adequate foliar coverage to control the small sprouts.

Brush and herbaceous competition can be treated in the first growing season after the burn with either soil active herbicides or with hand-directed spray applications. Some soil active herbicides such as hexazinone will control re-sprouting brush and hardwoods to some extent, but generally don't provide enough control to be a one-time treatment option, especially where there is a big component of hardwoods and re-sprouts. In most cases there will be the need for some conifer release spray applications by year 3 after planting. Effective control with the site prep sprays will help minimize the need for follow-up applications. In remote areas there may not be adequate road access to allow ground based herbicide applications. In these areas the only options are to aerially apply herbicides or to use manual weed control.

Seedling Delivery from the Nursery to the Roadside

The sheer number of seedlings needed for the reforestation of a large wildfire presents many challenges for the reforestation team. One of the challenges is transportation of the large number of seedlings from the nurseries to local cold storage facilities and from the storage facility to the planting sites. Reducing the total number of seedling pallets that need to be transported and stored will improve efficiency This can be achieved by a) reducing the number of trees per acre (TPA) that are planted, or b)by using the smallest suitable seedling size, or c)by utilizing both strategies. Reducing the trees per acre will have a dramatic effect on the total number of trees planted. For example, a 3,000 acre burn planted at 12 feet x 12 feet spacing (302 trees per acre) will require 906,000 total trees. That same area planted at 18'x18' spacing (134 TPA) would only require 402,000 trees. In addition, to reducing the number of pallets that would need to be transported and stored, this strategy, where appropriate, would also significantly reduce many other complications and costs encountered in large acreage reforestation projects, including the amount of seed needed, nursery growing space, and the number of planting crews used during a short planting season window. Planting fewer trees per acre may also reduce the need for pre-commercial thinning in the following decade (7 to 10 years after planting) thereby moderating scope and cost of pre-commercial thinning and resulting slash loading across thousands of acres. However, it may not be advisable to plant on very wide spacing with more difficult to establish species or harsh sites as stocking levels will be quite low if there is much mortality.

Because reforestation with Ponderosa Pine (PP) and Jeffrey Pine (JP) typically results in very high survival rates when all of the proper reforestation steps are followed, a good option to consider is wider planting spacing of 134 TPA (18 feet by 18 feet spacing) if the ultimate desired forest spacing is near 100 TPA and the area is to be planted back to PP or JP. In areas where the dominant species is Douglas-fir and/or true fir, relatively higher planting densities are usually necessary to achieve the desired stocking densities for those species. Some recent efforts on USFS land where lower tree densities are desired (often based on land allocation) employ a "cluster" or diamond planting scheme on wide spacing in which multiple trees were planted at each planting site. For example, planting 3 seedlings close together in a group with 27 foot spacing between groups would require planting only about 180 trees per acre. If the goal is to have at least one tree remaining in each group, the stand will soon have spacing more similar to the historical spacing of a mature forest. This approach addresses the possibility of mortality at each planting site and allows multiple species to be planted at each site. It also could serve to reduce the cost of manual release in rehabilitating burned sites projects where herbicide use is restricted as the number of manual release circles per acre is reduced.

Using the smallest suitable size of seedlings can reduce the number of pallets needed for transport and storage. Small containerized seedlings or 1-0 bare root are packed at higher numbers per package and require less space in storage than similar numbers of larger seedlings. Cell sizes should be at least styro-4 for PP and JP, and no smaller than styro-6 for Douglas-fir, red fir (RF), white fir (WF), incense cedar (IC), and sugar pine (SP). The following table shows how many trees per load that a 53 foot refrigerated semi-trailer can haul and the influence of stock type on that number for a very commonly used nursery in California.

Table 12.1 Tree seedlings per transportation units (box, pallet, semitruck)

Cell Size	Trees/Box	Boxes/Pallet	Trees/Pallet	Pallets/Semi	Trees/Semi
St-4	400	18	7200	48	345,600
St-5	320	18	5760	48	276,400
St-6	270	18	4860	48	233,280
St-8	240	18	4320	48	207,360

Refrigerated Vans

If there is not room or facilities to store seedlings at the nursery for a project, refrigerated vans can be used to transport seedlings from the nursery to a commercial size cold storage facility designed and equipped to properly store seedlings and easily handle pallets of seedling boxes.

Refrigerated vans can also be used to store seedlings for short periods of time in order to supply the daily production needs of one or more planting crews because the nursery or other cold storage facility is not within a reasonable distance of the project area. Using the smallest stock type that is appropriate to plant might reduce the number of refrigerated vans that would need to be rented and maintained for the duration of the planting operations. Refrigerated vans used for cold storage must be monitored daily to make sure the refrigeration unit is operating properly and inspected to check van temperature, oil and fuel levels (if the refrigeration unit is fuel powered and not electricity), fan(s) and refrigerator coils, and other critical components. Also, it is prudent to line up and have on call a mechanic experienced with repairing these particular mobile refrigeration. Daily monitoring of the refrigerated vans and ready access to an experienced repair person is critical so that if (or more likely, when) a unit malfunctions it can be repaired within 24 hours. On large projects where refrigerated vans are used for temporary cold storage to supply daily planting needs, it is critical for the forester overseeing the project to plan and coordinate well with the nursery and monitor the production and progress of each planting crew supervisor on a daily basis. This is necessary so that each crew will have a ready supply of the specific seedling stock types, seed lots and species that will be planted each day.

On a 14,000 acre burned area planting project a private forest manager planted 4,000 to 6,000 acres per year over a three year period, using an average of four 12 to 14 person planting crews and renting 3 refrigerated vans. One tractor/trailer driver was hired to rotate the vans loaded with seedlings from the nursery to a secure location within a relatively short distance of the project area. Two vans were loaded at the nursery with the specific seedling lots that would be needed for the first week of planting and transported to a central, temporary storage location prior to the start of the planting project. Every morning each of the four crews loaded the number and lots of seedlings from the van used for each day's planting. The reforestation project manager coordinated with the nursery manager, tractor/trailer driver and planting inspectors assigned to each crew so that the third van was scheduled for loading and delivery of seedlings from the nursery to the temporary storage location and an empty van could be picked up by the tractor driver. This coordination and scheduling was done to rotate vans such that each planting crew could readily load a sufficient number of seedlings each day for each species, seed lot and stock type that were scheduled for planting into each particular area. By daily communication with the planting inspector for each crew, the project manager could instruct the nursery to load the vans in a specific order with specific pallets of seedling lots at specific locations within the van. This allowed for seedling boxes to be unloaded just once on the morning of planting and not unloaded and reloaded with the crews having to rummage around in the vans looking for the specific seedling lots (species/stock type/elevation) scheduled for planting each day. When ordering, the project manager would instruct the nursery to load the seedlings that were to be planted last to be loaded first towards the front of the van so that seedlings scheduled to be planted first would be at the back of the van closer to the doors. It is advisable to map pallet locations by seed lot and species within the van when ordering and/or loading to facilitate and improve seedling handling efficiency.

Freezing Seedlings

Freezing conifer seedlings for long term storage is a good way to arrest mold development and is the preferred way to store seedlings longer than three months. When freezer storage is used, it is important to have an area to thaw the seedlings prior to the anticipated planting date. If the storage facility is located in an area where the ambient temperatures are very low, thawing may be impossible. In that case, it would be advisable to place the reefer van at a lower, warmer elevation to facilitate the thawing process. Thawing time can vary widely and is dependent on the packaging, stock type, moisture content of the containerized seedling, air flow around the containers and the ambient temperature. Opinions and experience vary about the best way to thaw seedlings for optimal survival. Several researchers report that while the stock is either being frozen or thawed the air temperature should not be more than 3.6 degrees above or below freezing. This would be considered a slow thaw and could take up to a month or longer for the seedlings to be ready for out plant. Many other practitioners report that a quick thaw at an ambient temperature of 50-65^{o} F degrees provides satisfactory results and is much more predictable with thaw duration lasting a week or less. Boxes on pallets should be separated slightly to allow air flow around individual boxes to help thaw the boxes more evenly. Spacers can be placed between the boxes in the nursery during packing if the plan is to freeze the seedlings at the time of packing. This also facilitates a more rapid freeze. Thawed trees should be planted as soon after thawing as possible.

Seedling Delivery from the Roadside to the Field and Planting

In burns that have limited access, the reforestation team may be faced with getting seedlings to planting crews far away from roads. Using wide spacing and small nursery stock will help, but delivery of the seedlings to the planting site may require extra effort. In very steep terrain using a tree yarder may facilitate seedling delivery. The tree yarders can deliver boxes of seedlings to sites as far away as 2,000 yards by suspending them from cables, provided there are not many obstacles such as standing timber or rock outcroppings that cause deflection problems. Planting crews can then either bag up along the tree yarder's corridors or crew members can be employed as packers to deliver to more remote portions of the unit that are inaccessible to the yarder. In this type of terrain the combination of yarding and packers can extend the plantable area significantly.

In areas that are less remote, using ATV/UTV's is a good way to get seedlings to the planting crews when the roads are not passable by pickup due to wet weather or snow (Figure 12.1). ATV's can also access areas that are not roaded using skid trails and open ridgelines. Equipment that is in the area doing salvage operations could be used to open trails or make trails on ridgelines for such planting access. Working closely with the foresters that are managing the salvage operations will ensure the best possible access for planting.

Figure 12.1 UTV delivering seedlings to planting crew via skid trail.

Some extreme circumstances may be encountered where neither road access nor terrain allow any mechanical access. Delivery of the seedlings by helicopter can be evaluated, but it is a very expensive option. Another possibility is to arrange a big enough planting crew so that some personnel can be used to transport tree boxes long distances from the nearest road to the actual planting site (Figure 12.2). In the case where as many packers are needed as planters, it may double the cost of planting, but, given the absence of other options, is likely the best way to reforest this type of terrain. Utilizing some combination of these options can extend the plantable areas of a large wildfire significantly. In roadless areas that have burned making large planting efforts unfeasible, the USFS has started planting "founder stands" where a small portion of the high severity burn area will be planted as an island. The hope is to establish a seed source for future natural seeding where there is none.

Figure 12.2 Worker packing trees in the Moon Fire.

Managing Sediment Transport within Wildfire Units

Large wildfires often result in additional sediment discharge into waterways for a number of reasons. Stream flow should be expected to increase sharply after a high intensity fire as the vegetation that normally intercepts precipitation and protects the soil is gone resulting in more water flow into channels. Springs and wet areas may appear that were not evident pre-fire and generate sediment transport. Many, soils after a wildfire may exhibit hydrophobic characteristics that repel water and cause a higher level of surface water flow during the first heavy rains of the season after the burn. It is important to consider actions to reduce additional sediment transport associated with logging and reforestation activities.

Salvage logging operations can help break up the continuity of hydrophobic conditions through scarification hydrophobic conditions, similar to the effect mechanical site prep such as tilling. The increased infiltration rates associated with these activities can reduce the rate of sediment transport (James & Krumland, 2018). Logging will also commonly result in the deposition of a layer of slash that can help stabilize soil movement. Planning some of the land alterations along the contours can also prevent sediment delivery into streams. In regards to the application of herbicides, it is inadvisable to immediately broadcast herbicides to hydrophobic soils or soils that are undisturbed by salvage operations after a fire as offsite movement would be possible in the absence of effective infiltration. An alternative is to apply herbicides by hand at low rates per acre directly to the small, emerging foliage of re-sprouting brush species that are susceptible to the particular herbicide at that early stage of resprouting. Applying spray on a limited site specific basis will significantly reduce the chance of movement off-site.

Burns that have elevated erosion hazard areas should be evaluated for additional mitigation measures to address the possibility of erosion and sediment discharge. The Pest Control Advisor/Forester should evaluate the choice of herbicide to address the potential of creating bare ground in erodible soils. Use of foliar contact rather than soil active herbicides and species-specific, rather than broad spectrum herbicides will retain additional vegetative cover that can reduce potential sediment transfer. Another measure would be to allow the area to re-vegetate for a period of time to help stabilize the soil and minimize movement. It is critical that the dead vegetation resulting from this control method be left on site to effectively utilize this extra protection. Follow-up tilling may be beneficial, but subsequent mechanical equipment clearing to bare soil should be avoided. Leaving vegetated buffer strips along stream courses and areas that have slides or gullies is another method to help stabilize areas to prevent even greater erosion (Figure 12.3). It is important to recognize, that the presence of competing vegetation can impact tree seedling survival and future growth. Any intentional retention of competing vegetation or delay in treatment can significantly increase costs, threaten plantation success, and unintentionally result in an un-forested landscape unless the prescribed series of treatments have accounted for that action.

Figure 12.3 Unsprayed vegetative strip on edge of eroded feature.

If seedlings are growing in the nursery for other projects that can be delayed to another year but are suitable for the area burned in the fire, then another strategy is to utilize them immediately in areas planned as buffers to herbicide use. This allows for planting these newly designated stream buffer units in the fall or spring immediately after the fire when competing vegetation has not yet established roots, and it can facilitate first year conifer seedling survival. Treating the competing vegetation might then just require a directed foliar spray within four or five feet of widely spaced conifer seedlings with an herbicide that is not mobile in soil. If done properly this could provide sufficient vegetative cover for the buffer zone while providing for successful reestablishment of a conifer over story.

Conclusion

When carefully analyzed, planned, executed and funded, the reforestation of large burns can successfully regenerate the fire-damaged landscape. When conducted in a timely manner and with a well co-ordinated series of treatments, it can help alleviate the long-term wildfire effects on the affected watershed, restore the previous forest more quickly than if left alone, and minimize the total costs and amount of herbicides necessary for that success.

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References

Dennison, P. E., Brewer, S. C., Arnold, J. D., & Moritz, M. A. (2014). Large wildfire trends in the western United States, 1984–2011. *Geophysical Research Letters, 41*(8), 2928-2933. doi:10.1002/2014GL059576.

James, C. E., & Krumland, B. (2018). Immediate Post–Forest Fire Salvage Logging, Soil Erosion, and Sediment Delivery. *Forest Science, 64*(3), 246-267. doi:10.1093/forsci/fxx013.

Leverkus, A. B., Rey Benayas, J. M., Castro, J., Boucher, D., Brewer, S., Collins, B. M., . . . Gustafsson, L. (2018). Salvage logging effects on regulating and supporting ecosystem services — a systematic map. *Canadian Journal of Forest Research, 48*(9), 983-1000. doi:10.1139/cjfr-2018-0114.

McIver, J. D., & Starr, L. (2000). *Environmental effects of postfire logging: literature review and annotated bibliography. PNW-GTR-486.*

Miller, J. D., H. D. Safford, M. Crimmins, A. E. Thode. (2009). Quantitative Evidence for Increasing Forest Fire Severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada, USA. *Ecosystems, 12*(1), 16-32. doi:10.1007/s10021-008-9201-9.

Miller, J. D., & Quayle, B. (2015). Calibration and validation of immediate post-fire satellite-derived data to three severity metrics. *Fire Ecology, 11*(2), 12-30.

Miller, J. D., & Safford, H. D. (2017). Corroborating evidence of a pre-Euro-American low to moderate fire severity regime in yellow pine-mixed conifer forests in the Sierra Nevada, California, USA. *Fire Ecology, 13*(1), 58-90. doi:10.4996/fireecology.1301058.

Miller, J. D., & Thode, A. E. (2007). Quantifying burn severity in a heterogeneous landscape with a relative version of the delta Normalized Burn Ratio (dNBR). *Remote Sensing of Environment, 109*, 66-80.

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, S. L., Collins, B. M., Fettig, C. J., Finney, M. A., Hoffman, C. M., Knapp, E. E., . . . Wayman, R. B. (2018). Drought, Tree Mortality, and Wildfire in Forests Adapted to Frequent Fire. *BioScience*, bix146-bix146. doi:10.1093/biosci/bix146

Stevens, J. T., Collins, B. M., Miller, J. D., North, M. P., & Stephens, S. L. (2017). Changing spatial patterns of stand-replacing fire in California conifer forests. *Forest Ecology and Management, 406*, 28-36. doi:https://doi.org/10.1016/j.foreco.2017.08.051

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