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.

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.

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.

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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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

Prepared by CalForest Nurseries, Etna, CA.