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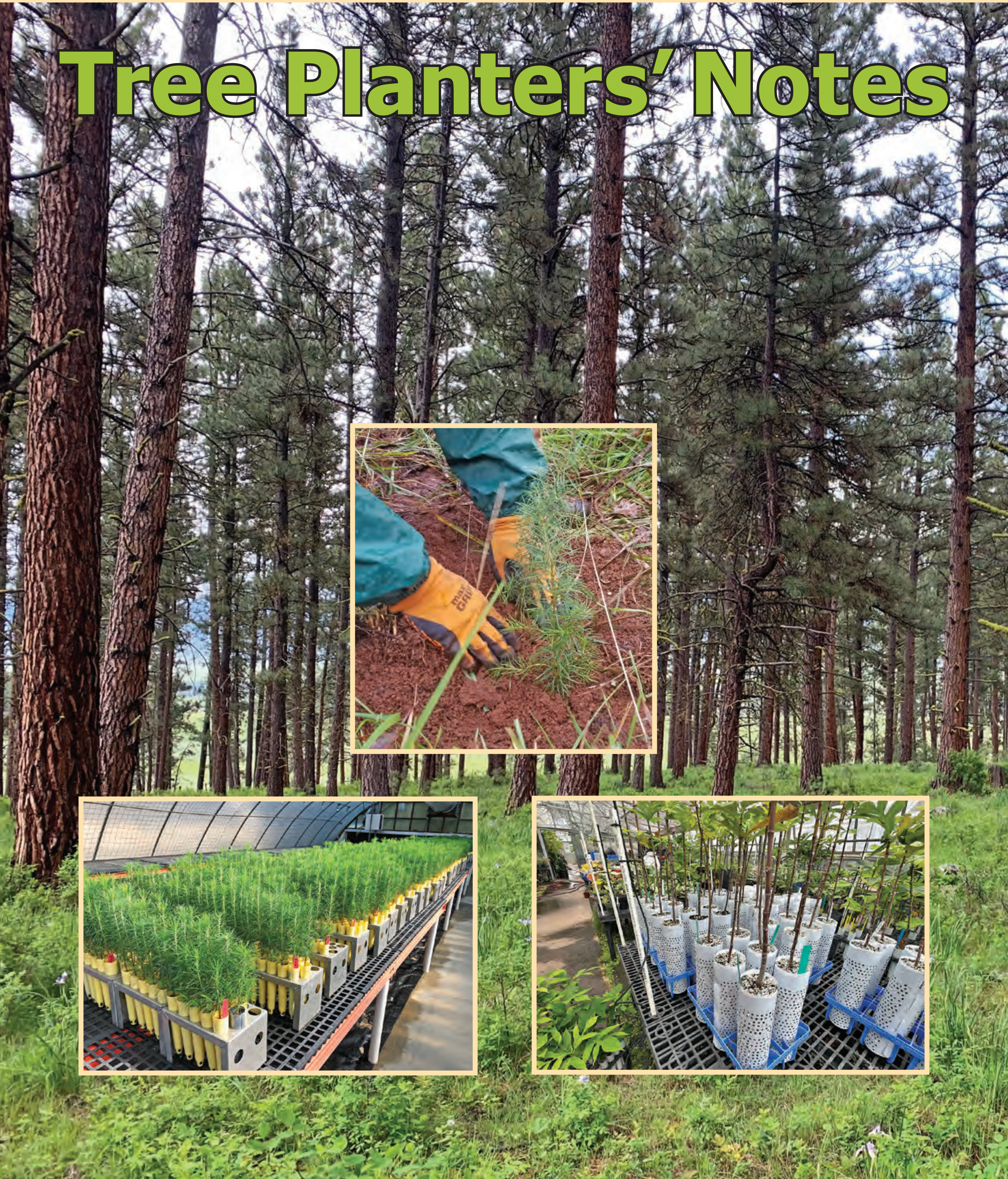
# Tree Planters' Notes



***Tree Planters' Notes*** **(TPN) is dedicated to technology transfer and publication of information relating to nursery production and outplanting of trees and shrubs for reforestation, restoration, and conservation.**

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**Editor: Diane L. Haase**

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Fall 2023

# Dear TPN Reader,

Welcome to the fall 2023 issue which consists of eight articles covering a diversity of topics. I'm especially pleased about the article describing Oregon's past, current, and future reforestation activities for TPN's series, "Tree Planting State by State" (Christiansen et al., page 4). McKeever (page 28) gives an overview of the history and activities at the Resistance Screening Center in Asheville, NC, where staff members expose seedlings to disease and evaluate their responses. Evans (page 35) shares strategies for stabilizing streambanks by establishing willow poles to prevent erosion during high water flow events in New Mexico. Mora et al. (page 41) describe development of an innovative, low-cost container that produces high-quality plants, can be easily shipped, and is available open-source. This issue contains two more articles in the series to provide guidance for seed transfer of tree species within the Eastern United States: shortleaf pine (Pike and Nelson, page 48) and longleaf pine (Pike and Nelson, page 55). Kiiskila et al. (page 62) describe a study to examine the effects of interim cold-storage duration on root growth of Douglas-fir and western redcedar seedlings lifted in late summer. Lastly, the issue concludes with the annual report of seedling production in the United States (Pike et al., page 73).

I'm certain you'll find something useful and interesting within this issue!

Diane

Diane L. Haase

*I'm planting a tree to teach me to gather strength from my deepest roots.*
~ Andrea Koehle Jones

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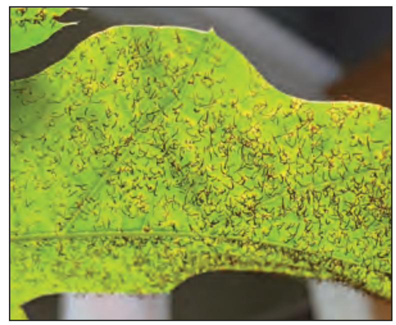

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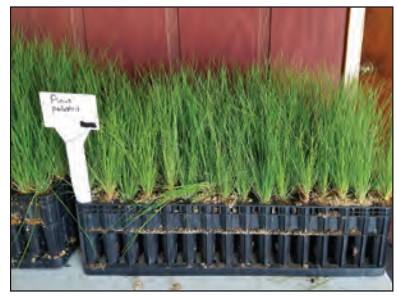

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# Reforestation in Oregon

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## Abstract

Oregon's forests are diverse, ranging from coastal temperate rainforests in the west to dry pine forests in the east. Approximately 60 percent of Oregon's forests are publicly owned, with the remainder in private or Tribal ownership. Reforestation activities vary considerably among ownerships and forest types. In western Oregon, most reforestation is accomplished by industrial forest landowners planting nursery-grown seedling following regeneration harvest. Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) is by far the most commonly planted species. Reforestation has declined on Federal lands in Oregon since the mid-1990s following adoption of the Northwest Forest Plan and the resulting reduction in regeneration harvests. Reforestation needs are increasing, however, on Federal forest lands in the State due to the recent increase in large, stand-replacing wildfires. In eastern Oregon, landowners primarily rely on natural regeneration and interplanting for reforestation. Over the past decade, 40 to 80 million seedlings have been planted annually in Oregon, most of which are conifer species. Ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson) is the most commonly planted species. Current reforestation challenges include increased seedling demand following wildfire, nursery capacity, and increases in temperature and drought that make tree establishment more difficult, especially on harsh sites. Future reforestation practices require addressing the challenges of adapting species, seed source, and stock type selection in a warming climate.

## Oregon's Forests

Oregon is often recognized for its beautiful forests (figure 1) across its diversity of ecosystems. In fact, nearly half of Oregon is forest land, totaling 29,656,000 acres (12,001,357 ha) (figure 2). These forests provide significant support to the State's economy and serve to protect water, wildlife, soil, and other resources.

**Figure 1.** The west Cascade Range has a variety of native tree species present but is largely dominated by Douglas-fir. (Photo by Alicia Christiansen, 2018)

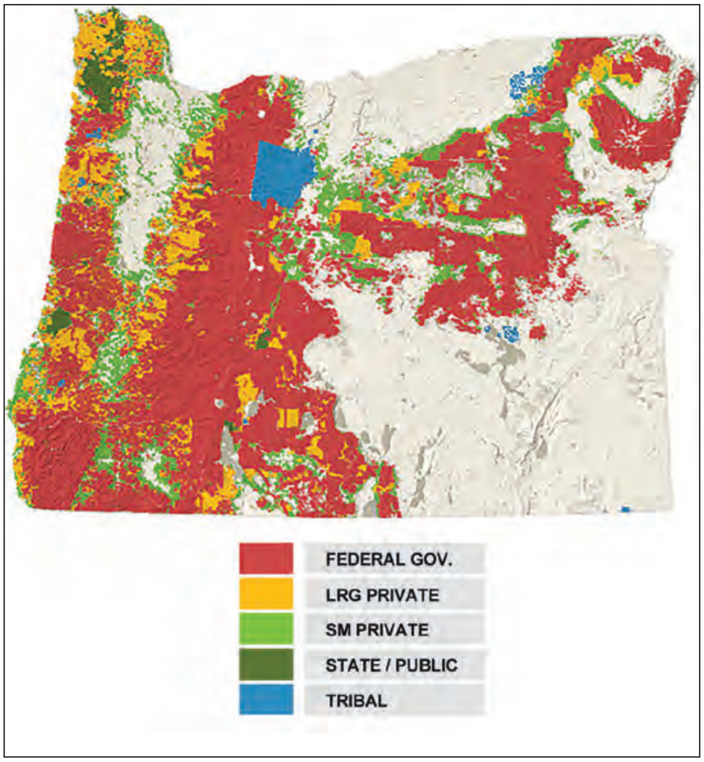


**Figure 2.** The majority (64 percent) of Oregon forests are owned by Federal agencies. (Source: Oregon Department of Forestry)

## Forest Ownership

Oregon's forests are managed by both private and public entities, with 61 percent managed by the Federal Government (48 percent by U.S. Department of Agriculture [USDA], Forest Service and 12 percent by the U.S. Department of the Interior [DOI], Bureau of Land Management), 34 percent by private owners, 4 percent by State and county governments, and 2 percent by Native American Tribes (figure 3) (Oregon Forest Resources Institute 2023d).

The 14 million acres (5,665,599 ha) of forest land managed by the USDA Forest Service is distributed among 11 national forests across western and eastern Oregon. The State, Private, and Tribal Forestry division of the USDA Forest Service's Pacific Northwest Region provides technical and financial assistance for family forest landowners through State forestry agencies and other partners to implement resource management activities, projects, and educational outreach programs (https://www.fs.usda.gov/r6). The Bureau of Land Management manages 15.7 million acres (6,353,565 ha) of forest land for multiple use and sustained yield across the landscape. Its western Oregon ownership covers 2 million acres (809,371 ha) of forest in a checkerboard pattern (LaLande 2022).

The State of Oregon owns and manages 942,000 acres (381,213 ha) of forest land. Oregon's 36 counties and municipalities own and manage a total of 187,000 acres (75,676 ha) of forest land (Oregon Forest Resources Institute 2023d). The Oregon Department of Forestry serves Oregonians by helping keep forests healthy, working, and sustainable. These objectives include protection of 16 million acres (6,474,970 ha) of Oregon's public and private forest lands from wildfire (Oregon Department of Forestry 2023).

Private landowners in Oregon can be broken into two categories: large private landowners, who own more than 5,000 acres (2,023 ha), and small private landowners, who own less than 5,000 acres. Private industrial forest owners or other landowners of large, forested tracts primarily manage for wood production and own 6.4 million acres (2,589,988 ha) of forest in the State. Small private landowners manage for multiple resources and benefits and own 3.7 million acres (1,497,336 ha) in Oregon (Oregon Forest Resources Institute 2023d).

Tribal Governments own and manage 480,000 acres (194,249 ha) of forest land in Oregon. Specific management techniques and goals vary across Tribes and regions (Oregon Forest Resources Institute 2023d).

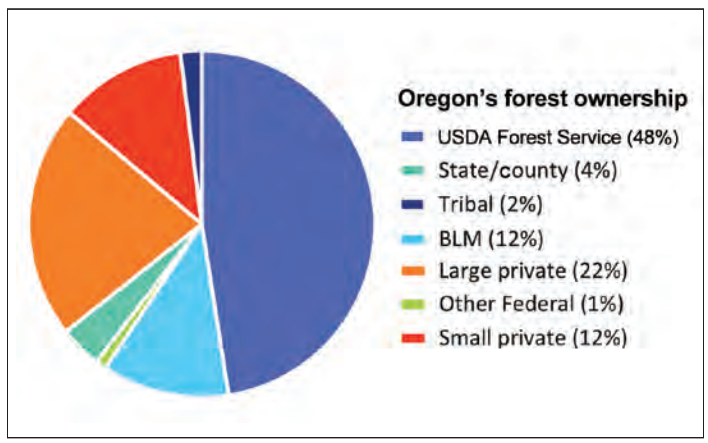


**Figure 3.** Oregon forests are owned by Federal, large private, small private, State/county, and Tribal entities. (Adapted from Oregon Forest Resources Institute, 2018)

## Timber Harvest

Almost 30 million acres (12,140,569 ha) of Oregon are covered in forests, a number that has held steady for nearly 100 years (figure 4). While the Federal Government manages the majority of forest land in the State, only a small portion of Oregon's timber harvest occurs on those lands, most of which

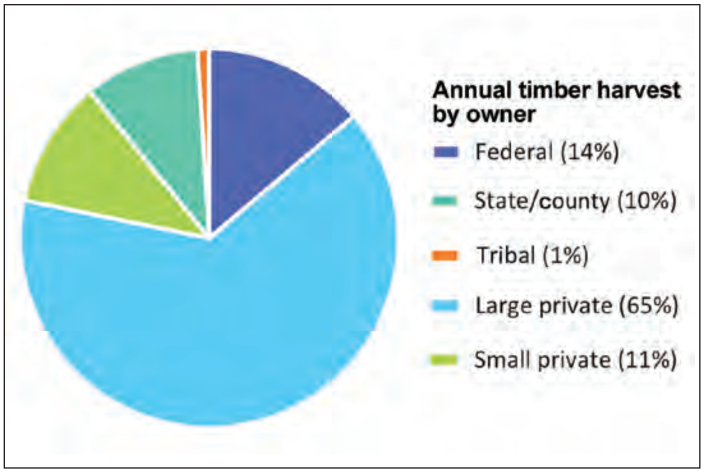


**Figure 4.** Private timberlands account for 75 percent of the annual timber volume currently harvested in Oregon. (Adapted from Oregon Forest Resources Institute, 2020)

is from thinning. Private timberlands account for about 76 percent of the annual timber volume currently harvested in Oregon (Oregon Forest Resources Institute 2023d).

Over the past 20 years, timber harvest levels from both public and private forest lands have been relatively stable, except for a decline during the Great Recession (2007 to 2009). Due to the collapse of the housing market and reduction in demand for U.S. lumber, timber harvest in Oregon was only 2.7 billion board feet in 2009, the smallest harvest since the Great Depression in 1934 (Gale et al. 2012; Oregon Forest Resources Institute 2023d). By 2013, the market rebounded to approximately prerecession levels. From 2017 to 2021, Oregon timber harvest averaged approximately 3.8 billion board feet. This amount was increased after the 2020 Labor Day Fires due to postfire salvage logging on private land (Oregon Forest Resources Institute 2023d).

## Reforestation Programs and Assistance

To help offset the high costs associated with reforestation activities for private, nonindustrial forest landowners, financial assistance is often available. These programs offer technical and financial assistance as cost-share or partial compensation through direct reimbursement for costs incurred when implementing certain management activities that promote stewardship, enhancement, conservation, and/or restoration. At the Federal level, funded by the USDA under the Farm Bill, programs are administered by either the Natural Resources Conservation Service or the Farm Service Agency. Federally funded programs that support tree planting and other reforestation activities include the Environmental Quality Incentives Program, Conservation Stewardship Program, Emergency Forest Restoration Program, and other conservation programs under the Farm Bill.

## Technical Assistance and Educational Resources

The Oregon Department of Forestry (ODF) enforces the Oregon Forest Practices Act and other rules and laws designed to conserve Oregon's forests. ODF stewardship foresters are available across the State to provide technical assistance. ODF also assists private owners of forest land and works with urban communities to sustain Oregon's "lived-in" forests in urban areas, city parks, neighborhoods, and other spaces. In addition, ODF administers the Small Forestland Owner Office, which assists small landowners by providing technical assistance, supporting services, and forest land incentive programs (https://www.youtube.com/@OregonDepartmentofForestry/about).

Oregon State University (OSU) Extension Service is the go-to resource for the expertise and knowledge every Oregonian needs to live healthy lives, nurture the State's ecosystems, and play a vital role in Oregon's vibrant communities. The OSU Extension Service's Forestry and Natural Resources Program is run by a team of county agents, regional and statewide specialists, program coordinators, and educational program assistants spread across the State. Each person focuses on a specific region or subject matter, providing a collective expertise in areas including forest management, reforestation, silviculture, harvesting, Christmas trees, fire, forest health, and more. The Forestry and Natural Resources team values strong community partnerships and offers a wide variety of science-based information, resources, and educational opportunities for forest landowners, contractors, forestry professionals, youth, and the general public to learn about forestry and natural resource topics through a variety of methods, including workshops, seminars, field tours, one-on-one site visits, publications, videos, podcasts, and more (figure 5). Statewide volunteer educational programs include Master Woodland Managers, Women Owning Woodlands Network, Oregon Master Naturalist, and Oregon Season Trackers (https://extension.oregonstate.edu/about).

The Oregon Forest Resources Institute (OFRI) was created by the Oregon Legislature in 1991 to support and enhance Oregon's forest products industry. A portion of the State's forest products harvest tax revenue helps support OFRI's educational programs. OFRI is a State agency and provides forest and forest management education programs (many of which are free of charge) for the general public, K–12 teachers and students, and forest landowners. OFRI's programs include information about forest-related topics of broad public interest, such as the benefits of wood products, clean water, responsible sustainable forest management, minimizing fire risks, carbon and climate change, and protection of wildlife habitat (Oregon Forest Resources Institute 2023a).

The Oregon Small Woodlands Association (OSWA) is a member-based association that represents small woodland owners in Oregon. Regular members own between 1 and 5,000 acres (0.4 and 2,023 ha) of land with trees growing on the property, and associate membership is available for those who do not own woodlands in Oregon but are interested in the best interests of small woodland owners (figure 6) (https://knowyourforest.org/landowner-assistance).

The Oregon Tree Farm System (OTFS) is a nonprofit organization affiliated with the American Tree Farm System and American Forest Foundation. The purpose of OTFS is to help family forest landowners manage their lands with the goals of conserving forests, water, and wildlife while promoting natural resource-based recreational opportunities. Landowners with 10 or more acres (4 ha) that are forested or capable of supporting trees are eligible to join OTFS. Members that exemplify sustainable forest management are recognized and celebrated through the Tree Farmer of the Year recognition program (https://www.otfs.org/about-otfs).

Oregon is home to 45 Soil and Water Conservation Districts (SWCDs) (https://www.oregon.gov/oda/programs/NaturalResources/SWCD/Pages/SWCD.aspx), which are special districts that provide for the conservation of the State's renewable resources. SWCDs work with local landowners and residents, natural resource organizations, natural resource users, and local, State, and Federal governments.

**Figure 5.** OSU Extension forestry agents visit with landowners on their properties, providing information and resources to help landowners reach their management goals. (Photo by Lynn Ketchum, Oregon State University, 2016)

**Figure 6.** Tours of small woodland properties, such as this one in Roseburg, OR, is one of many kinds of events landowners can participate in as members of the Oregon Small Woodlands Association. (Photo by Alicia Christiansen, 2018)

SWCDs work to control and prevent soil erosion, conserve and develop water resources and water quality, preserve wildlife, conserve natural beauty, and promote collaborative conservation efforts to protect and enhance healthy watershed functions. SWCDs in Oregon are governed by an independently elected board of directors.

There are 55 watershed councils in the State represented by the Network of Oregon Watershed Councils (https://www.oregonwatersheds.org/). These Councils are based in local communities (both rural and urban) and vary in location, size, and organizational structure. Councils work throughout the State with landowners, community members, companies, industries, elected officials, and municipal and State agencies. Councils conduct a wide variety of conservation projects to restore and enhance the waters and lands for native species and people. These projects include improving fish passages, removing invasive weeds, and creating water storage opportunities in forests and wetlands.

## Tax Credits

In some situations, tax credits and incentives are available at both the State and Federal levels for costs incurred related to qualifying reforestation activities. Current credit and incentive opportunities can be found at the State level through the Oregon Department of Revenue, and at the Federal level through the Internal Revenue Service (IRS).

## Oregon Forest History Highlights

- 1911—The Oregon Legislature established the Oregon Department of Forestry to reduce damage from forest fires on private lands.
- 1929—The Oregon Reforestation Law was established and considered one of the most progressive forestry laws in the United States. This law was a forerunner of other reforestation laws in the United States during the 1940s and 1970s.
- 1941—Oregon adopted the Oregon Forest Conservation Act, which addresses fire protection and reforestation. This act requires State and private forest lands to be reforested after a timber harvest by leaving two seed trees per acre for natural regeneration.
- 1941—Industrial Forestry Association, now IFA Nurseries, started its first private conifer seedling nursery in the Western United States. Since then, it has grown more than 1.5 billion seedlings for customers throughout the Northwestern United States and British Columbia.
- 1966—The IFA-Progressive Tree Improvement System was established. This organization was run jointly by the USDA Forest Service's Pacific Northwest Research Station and the Industrial Forestry Association.
- 1971—The Oregon Forest Practices Act was enacted by the Oregon Legislature, making Oregon the first State to create a comprehensive set of laws governing the practice of forestry. This act replaced the 30-year-old Forest Conservation Act and established rules and guidelines for landowners and timber operators regarding timber harvest, chemical use, slash disposal, reforestation, road construction and maintenance, and other activities that could impact soil, fish, wildlife, and water in Oregon's forests. The act continues to be revised, and additional rules have been added periodically to reflect new scientific data, new operating technology, and new forestry practices that further help protect forests, water quality, and wildlife habitat.
- 2022—The Private Forest Accord was signed into law after several months of facilitated negotiations between conservation and fisheries groups, timber companies, and the Oregon Small Woodlands Association. This agreement established regulatory changes aimed to enhance protections for aquatic habitat such as setting new standards for forest roads and culverts to remove barriers to fish traveling upstream and expanding the width of required buffers along streams where logging is prohibited to help keep water cold and clean.

### Forestry Cooperatives at Oregon State University's College of Forestry:

- 1982—The Nursery Technology Cooperative (NTC) was established and was supported annually by State, Tribal, Federal, and private agencies and companies. Until it terminated in 2010, the NTC conducted nursery and field studies aimed toward improving seedling quality and outplanting success.
- 1983—The Pacific Northwest Tree Improvement Research Cooperative (PNWTIRC) was established. The PNWTIRC focuses on practical, applicable research in tree improvement and the engagement of public and private entities.
- 1984—The Stand Management Cooperative (SMC) was established in response to forest landowners in the Pacific Northwest (PNW) recognizing the need for a comprehensive research program to better understand the effects of silvicultural treatments from seedling to harvest on growth and yield and quality of conifer plantations. The SMC's goal is to provide a continuing source of consistent, high-quality data on effects of stand management practices, specifically on stands that have been under stocking control from an early age.
- 1986—The Northwest Tree Improvement Cooperative (NWTIC) was established (formerly IFA-Progressive Tree Improvement System). The cooperative was administered by a private forestry consultant, Daniels and Associates, until 2000 when it was transferred to OSU's College of Forestry. The main priority for the NWTIC is to promote and support tree improvement cooperatives in the PNW. As of June 2022, it serves 62 members and their distinct operations.
- 1988—The Hardwood Silviculture Cooperative (HSC) was established and functions as a multifaceted research and education program focused primarily on the silviculture of red alder (*Alnus rubra* Bong.) and mixed stands of red alder and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco).
- 1993—The Vegetation Management Research Cooperative (VMRC) was established as a reorganization from a previous vegetation management cooperative. Due to the onset of new reforestation regulations from British Columbia to California restricting the use of traditional modes of vegetation management (primarily herbicide use and burning), the VMRC research focus is to aid in reducing the overall use of herbicides in a manner consistent with the law, while still promoting increases in forest regeneration success.
- 1997—The Swiss Needle Cast Cooperative (SNCC) was established to address challenges to the management of Douglas-fir in Oregon and Washington caused by the Swiss needle cast epidemic.
- 2007—The Center for Intensive Planted-forest Silviculture (CIPS) was established with the goals to improve the economic and environmental performance of Pacific Northwest forests and to enhance the regional and global competitiveness of Pacific Northwest forest products.

*Sources: Magalska et al. (2022), Oregon Forest Laws (2023), Oregon Forest Resources Institute (2023b, 2023c), State of Oregon (2023).*

## The Oregon Landscape

The Oregon landscape is very diverse. Several different conventions exist for dividing Oregon into areas based on similar geographic and vegetative characteristics. Most simply (and commonly), the State is split in two—western and eastern Oregon—divided by the Cascade Range. However, many climatic, geographic, and vegetative differences exist within the western (moist) and eastern (dry) portions of the State (figure 7).

**Figure 8.** Douglas-fir is the primary species planted in the Oregon Coast Range. (Photo by Glenn Ahrens, 2009)

### Western Oregon

Western Oregon spans from the rugged Pacific Coast to the volcanic snow-capped western side of the Cascade Mountain Range. The Willamette Valley is nestled at the northern end of the State between the Coast and Cascade Ranges, and the Klamath Mountains lie to the south. Western Oregon's mountains were formed from volcanic activity of the tectonic plate Juan de Fuca, with the most recent major activity being the 1700 Cascadia earthquake. Forming the majority of Oregon's northern border, the Columbia River is one of North America's largest rivers and flooded much of Oregon during the Missoula Floods approximately 15,000 years ago. The incredibly fertile Willamette Valley formed largely as a result of this flood (Oregon Department of Geology and Mineral Industries 2009).

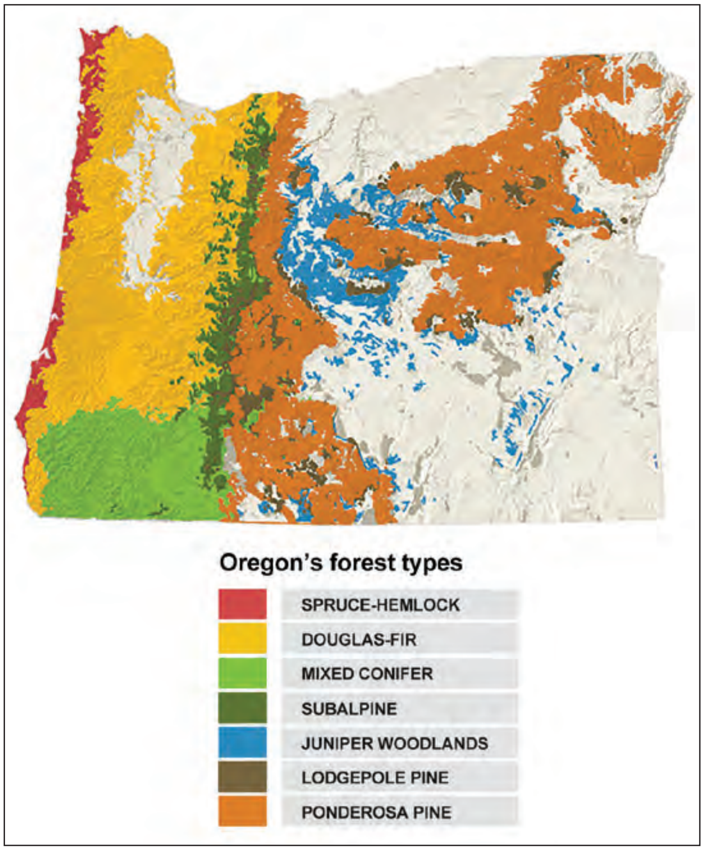


**Figure 7.** Oregon is home to some of the world's most productive forests, dominated by Douglas-fir on the west side of the Cascades. (Source: Oregon Forest Resources Institute, 2017)

The climate in the Coast Range is mild and moist. The marine influence provides for the warmest winters, coolest summers, and most annual rainfall in the State. The Willamette Valley experiences hot and dry summers with periodic summer droughts. The western Cascades vary in precipitation and experience winter snowfall as elevation increases. The Klamath Mountains have a strongly Mediterranean climate with generally mild, wet winters and warm, dry summers with increasing frequency of drought. Forests blanketing western Oregon range from temperate rainforest in the Coast Range, to subalpine in the Cascades, to mixed conifer in the Klamath Mountains.

#### The Douglas-Fir Forest Type

The most extensive forest type in Oregon is the Douglas-fir forest type that spans most of western Oregon, from the Coast Range to the western Cascades. The Coast Range (figure 8) runs parallel to the Oregon coast from the Oregon-Washington border to the Middle Fork of the Coquille River and consists of relatively low, but steep, mountains. Coast Range forests are dominated by Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), alongside western hemlock (*Tsuga heterophylla* [Raf.]

Sarg.), grand fir (*Abies grandis* [Douglas ex D. Don] Lindl.), and western redcedar (*Thuja plicata* Donn ex D. Don). Along the coast, the coastal variety of lodgepole pine (shore pine) (*Pinus contorta* Douglas ex Loudon), and Sitka spruce (*Picea sitchensis* [Bong.] Carrière) are present. Hardwoods found here include red alder (*Alnus rubra* Bong.), bigleaf maple (*Acer macrophyllum* Pursh), and black cottonwood (*Populus balsamifera* L. ssp. *trichocarpa* [Torr. & A. Gray ex Hook.] Brayshaw), among others. Further south in the Umpqua and Coquille watersheds, Oregon myrtle (also known as California bay laurel) (*Umbellularia californica* [Hook. & Arn.] Nutt.) is also present (Campbell et al. 2004, Jensen 2020, Oregon Forest Resources Institute 2020).

The Willamette Valley (figure 9) sits between 200 and 1,000 ft (61 and 305 m) in elevation and has the lowest percentage of forest land in western Oregon, as much of the area is agricultural or urban. Forests in the Willamette Valley are mostly in the foothills of the Coast and Cascade Ranges. The Douglas-fir forest in the Willamette Valley often includes red alder, Oregon white oak (*Quercus garryana* Douglas ex Hook.), bigleaf maple, and western hemlock. In some areas of the Willamette Valley, unique native populations of “valley pine” (ponderosa pine [*Pinus ponderosa* Lawson & C. Lawson] adapted to the wet growing conditions of the area) and grand fir can also be found (Campbell et al. 2004, Jensen, 2020, Oregon Forest Resources Institute 2020).

**Figure 9.** The Willamette Valley has the lowest percentage of forest land in western Oregon and is a matrix of urban, agricultural, and forested lands, as shown in this drone's eye view near Oregon City. (Photo by Peter Matzka, Oregon State University, 2015)

**Figure 10.** Forests on the western slopes of Mount Hood near Lolo Pass are dominated by Douglas-fir. (Photo by Glenn Ahrens, 2017)

In the Western Cascades (figure 10), Douglas-fir grows alongside western hemlock, western redcedar, white fir (*Abies concolor* [Gord. & Glend.] Lindl. ex Hildebr.), and grand fir at lower elevations. Hardwoods are often limited to riparian areas and include bigleaf maple and red alder. As elevation increases, Douglas-fir is intermixed with Pacific silver fir (*Abies amabilis* [Douglas ex Loudon] Douglas ex Forbes), mountain hemlock (*Tsuga mertensiana* [Bong.] Carrière), lodgepole pine, and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) (Campbell et al. 2004, Jensen, 2020, Oregon Forest Resources Institute 2020).

### The Sitka Spruce and Western Hemlock Forest Type

The Sitka spruce and western hemlock forest type grows adjacent to the Douglas-fir forest type in the small strip along the coastal fog belt and seldom stretches more than a few miles inland or a few hundred feet above sea level. Along with Sitka spruce and western hemlock, this forest type may contain western redcedar, Douglas-fir, red alder, and shore pine. In the far southern extent of this range, coast redwood (*Sequoia sempervirens* [Lamb. ex D. Don] Endl.), Oregon myrtle, and Port-Orford-cedar (*Chamaecyparis lawsoniana* [A. Murray bis] Parl.) are also found (Campbell et al. 2004, Jensen 2020).

### The Siskiyou Mixed-Conifer Forest Type

The most vegetatively diverse forest type in western Oregon is the Siskiyou mixed-conifer forest type, found in the Klamath-Siskiyou Mountain region (figure 11) of southwest Oregon. This area encompasses climatic, geomorphic, and vegetative elements from the Klamath Mountains, Cascades, and Coast Range. Forest trees found here tend to be those that tolerate hot, dry summers. Available soil moisture plays a big role in determining which trees are found at a particular site. Ponderosa pine, Oregon white oak, California black oak (*Quercus kelloggii* Newberry), and Pacific madrone (*Arbutus menziesii* Pursh) grow in the drier sites. Incense cedar (*Calocedrus decurrens* [Torr.] Florin), Douglas-fir, grand fir, sugar pine (*Pinus lambertiana* Douglas), and western white pine (*P. monticola* Douglas ex D. Don) grow in intermittently moist sites. Port-Orford-cedar and western hemlock grow in areas with a lot of moisture, such as seeps, springs, and streambanks. Southern Oregon forests often contain evergreen hardwoods such as Pacific madrone, golden chinkapin (*Chrysolepis chrysophylla* [Douglas ex Hook.] Hjelmqvist), and tanoak (*Notholithocarpus densiflorus* [Hook. & Arn.] P.S. Manos, C.H. Cannon, & S.H. Oh). In riparian areas with poor drainage or flooding potential, a different set of hardwoods are present, including white alder (*Alnus rhombifolia* Nutt.), red alder, black cottonwood, and Oregon ash (*Fraxinus latifolia* Benth.) (Campbell et al. 2004; Jensen, 2020; Oregon Forest Resources Institute 2020).

### The Hardwood Forest Type

Hardwood forests are found intertwined with the other forest types in Oregon and include many species of broadleaved trees. Generally, hardwoods grow as individuals or in small stands, rather than large continuous tracks as found in the Eastern United States. Oak woodlands are the primary hardwood forest type in Oregon and once spanned the Willamette, Umpqua, and Rogue River valleys of western Oregon. Many of these woodlands have been lost to urban development, agriculture, and more recently, vineyards. Oak woodlands are dominated by Oregon white oak, and in wetter areas, bigleaf maple will also be present. Hardwood forests in valley bottoms have a wide variety of species, including Oregon ash, red and white alders, bigleaf maple, black cottonwood, and, in southwest Oregon, will include golden chinkapin and Oregon myrtle (Jensen, 2020).

**Figure 11.** The Klamath and Siskiyou Mountains of southwestern Oregon contain a diverse mix of conifers and hardwoods. (Photo by Peggy Martin, OSU Extension Master Woodland Manager volunteer program)

## Eastern Oregon

Eastern Oregon's mix of landscapes includes high desert, mountains, and a portion of the Columbia Plateau. Forests are found in the Blue Mountains and other areas where precipitation is sufficient to support tree survival and growth. Complex geology and topography have resulted in a variety of soil types. The eruption of Mt. Mazama 7,700 years ago, which led to the formation of Crater Lake, deposited a thick layer of pumice in central Oregon, resulting in coarse-textured, relatively infertile soils. Across northeastern Oregon, the eruption deposited fine ash layers, leaving deep soils with higher moisture holding capacity resulting in higher site productivity (Oester et al. 2018).

Lying in the rain shadow of the Cascades, the eastern part of the State is much drier than the western part and typically has larger daily and annual temperature variations. The climate is characterized by hot, dry summers and cold, moist winters. Most of the annual precipitation (8 to 100 in [20 to 254 cm]) comes as snow. As elevation increases, precipitation also increases but temperatures drop. Summers are typically droughty, with 3 to 5 months of no significant precipitation. The severity of drought at a particular site depends on annual precipitation, elevation, soil moisture-holding capacity, and evaporative demand (Oester et al. 2018).

The net effect of varying soil types, temperatures, and elevations creates a complex pattern of forest types and growing conditions. Most privately owned forests in eastern Oregon are either ponderosa pine, lodgepole pine, warm-dry mixed-conifer, or cool-moist mixed-conifer (Oester et al., 2018).

### The Ponderosa Pine Forest Type

The ponderosa pine forest type (figure 12) is found in areas so dry that no other commercial tree species can successfully grow there. Western juniper (*Juniperus occidentalis* Hook.) is often found in the understory as seedlings and saplings and occasionally as medium-sized trees in the forest canopy. Ponderosa pine forests are fire dependent, with a historic fire history of 5 to 25 years. Frequent fire helped keep stocking levels low and stands open. Forest management practices, overgrazing, and a century of fire exclusion, however, have resulted in much greater stand densities, particularly of fire-intolerant species, than

**Figure 12.** The eastern Oregon ponderosa pine forest type is found in very dry areas where no other commercial species can grow. (Photo by Jacob Putney, 2022)

have occurred historically. Pine regeneration is frequently poor, due to long summer droughts, low site productivity, and long periods between cone crops. Natural regeneration success is highly dependent on spring moisture and maximum average summer temperature (Oester et al. 2018).

### The Lodgepole Pine Forest Type

Lodgepole pine dominates (more than 90 percent of all trees) in the lodgepole pine forest type. These forests occur on pumice flats, in frost pockets, or on high-elevation plateaus. Lodgepole pine forest types occur in areas with potential for heavy frost in the spring and summer when seedlings are actively growing. Lodgepole pine is extremely tolerant to frost, more so than other species found growing alongside it. This forest type is commonly referred to as "boom-and-bust" because periodic mountain pine beetle attacks that kill most of the existing stand are followed by intense, stand-replacing fires. Lodgepole pine is found in many mixed conifer forest types, and when it is the dominant pioneer species it might be replaced by more shade-tolerant species, such as grand fir or subalpine fir. Lodgepole is known to prolifically regenerate following disturbance, with frequent cone crops and an extensive seed fall (Oester et al. 2018).

### Mixed Conifer Forest Types

Many forest sites across central and eastern Oregon are occupied by mixed conifer forest types (figure 13), especially in places that are not limited by drought or spring and summer frosts. The warm-dry mixed-conifer forest type is typically dominated by ponderosa pine in young stands. In areas with deep soil, however, western larch (*Larix occidentalis* Nutt.) may be the pioneer species. Douglas-fir and grand fir commonly regenerate in the understory. On the east flank of the Cascades, incense-cedar and sugar pine are often present. Site productivity is higher in warm-dry mixed-conifer forest types than in ponderosa pine types (Oester et al. 2018). The cool-moist mixed-conifer forest type is typically dominated by lodgepole pine or western larch in early successional stages, with ponderosa pine, Douglas-fir, and grand fir often present. This forest type is home to more moisture-demanding and cold-tolerant species, including subalpine fir, western white pine, and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) (Oester et al. 2018).

## Tree Planting in Oregon

Reforestation activities are key for establishing healthy new forests (figure 14). When reforesting, landowners and managers should select appropriate site-preparation methods, seedlings, and post-planting care based on an evaluation of site conditions, goals and objectives, costs, and the intended future forest conditions. Reforestation requires careful planning early on, which makes subsequent management decisions easier and contributes to long-term success.

Based on annual reports from 2012 to 2021, estimated hardwood and conifer seedling production in Oregon averaged 61.2 million seedlings planted across an average of 17,800 acres (7,203 ha) annually (Haase et al. 2022). Annual reports are based on surveys, so estimates may vary depending on responses. The estimated planted acres for Oregon assumes 350 stems planted per acre (865 per ha).

**Figure 13.** Many forests in eastern Oregon, such as the Blue Mountains in the northeast, are dominated by the mixed conifer forest type. (Photo by Jacob Putney, 2021)

**Figure 14.** When planting trees, such as Douglas-fir shown here in Oakland, OR, it is important to plan early and carefully to help ensure long-term success. (Photo by Alicia Christiansen, 2019)

## Workforce

Reforestation jobs include all aspects of greenhouse and nursery seedling production, handling, transport, and planting (figure 15). Positions are typically seasonal, labor-intensive, and physically demanding. Planting jobs require flexibility to travel long distances and to work on steep and uneven terrain in adverse weather conditions. Job safety and equity issues can occur in this workforce.

Based on employment data from 2016 (Oregon Forest Resources Institute 2019), Oregon's forest sector includes over 60,000 jobs, with approximately 22 percent being forestry support, which includes nurseries, firefighting, forest health, fuels reduction, and reforestation. Many employers rely on the H-2B visa program to fill positions and meet labor needs. In 2018, a total of 82,961 migrant seasonal farmworkers were employed in Oregon's top three agricultural industries (crops, nurseries and greenhouses, and reforestation), 3,428 of which worked in reforestation (Rahe 2018).

## Reforestation Regulations

Under the Oregon Forest Practices Act (Oregon State Legislature 1971), reforestation in Oregon is required when a forest practice, such as timber harvest, reduces tree stocking below the minimum standards, which vary by site productivity. Different regulations apply following a nonharvest disturbance that causes stocking levels to fall below the minimum, such as an extreme weather event or wildfire. In the case of wildfire, where a majority of the forest stand has burned, the reforestation requirement is only triggered when the standing, burned trees are harvested. The minimum reforestation standards also apply to Oregon's land use laws. For example, Oregon offers special assessment programs to landowners to incentivize maintaining land as forest by reducing annual property taxes. These programs require that the property be managed primarily for growing and harvesting timber, and that minimum stocking levels are maintained within the required timeframes, regardless of the cause of low stocking levels (e.g., harvest, weather, or fire).

Minimum stocking requirements differ based on tree size and site productivity (table 1), which vary by forest type and region. Because measures for

**Figure 15.** Tree planting contractor positions are typically seasonal, labor-intensive, and physically demanding. (Photo by Jordan Benner, Oregon Forest Resources Institute, 2020)

**Table 1.** Minimum stocking requirements in Oregon vary by site class and tree size (adapted from Cloughesy and Woodward 2018).

| Site class | Seedlings (<1 in DBH) per acre | Saplings and poles (1 to 10 in DBH) per acre | Trees (>11 in DBH) per acre |
|---|---|---|---|
| High (classes I, II, and III) | 200 | 120 | 80 |
| Medium (classes IV and V | 125 | 75 | 50 |
| Low (class VI) | 100 | 60 | 40 |

DBH = diameter at breast height.
1 acre = 0.4 ha

minimum stocking requirement differ by tree size (i.e., seedlings, saplings/poles, and trees), an equivalent calculation was developed. This formula is particularly useful for uneven-aged stands and in partially harvested stands (Cloughesy and Woodward 2018).

New trees = Rule standard – [# Seedlings + (#Saplings/poles ÷ 0.6) + (Basal area ÷ 0.4)]

Where:

New trees = the minimum number of seedlings that must be established to meet the minimum stocking standard

Rule standard = minimum stocking standard for seedlings based on site class

# Seedlings = number of existing seedlings in the stand

# Saplings/poles = number of existing saplings/poles in the stand

Basal area = measured basal area of the stand

Landowners are required to initiate reforestation efforts within 12 months following harvest, and replanting must be completed within 2 years. Within 6 years after harvest, planted trees must be considered “free-to-grow.” To be considered freely grown, planted trees must be well-distributed, the appropriate species and form, vigorous, and tall enough to out-compete other vegetation. Landowners should plan ahead and work with a local ODF Stewardship Forester to ensure that standards are met in compliance with the Oregon Forest Practices Act (Oregon State Legislature 1971).

## Site Preparation

Following disturbance (e.g., harvest or wildfire), sites often require preparation, such as creating accessible planting areas, controlling competing vegetation, and exposing bare mineral soil, to facilitate successful regeneration (Fitzgerald 2008). Seedlings are especially vulnerable to resource availability during the first few years of growth; therefore, site resources such as water, light, temperature, and nutrients are critical to consider. There are several methods that can be used to effectively prepare a site for regeneration. The appropriateness of each method depends on the site conditions, amount of debris or slash, and existing vegetation.

Chemical treatments, such as herbicides, can be an effective method for controlling competing and unwanted vegetation on a site prior to planting. This approach is generally the most cost-effective and provides the longest term results. Depending on the site topography, accessibility, and location, herbicides can be applied either aerially (e.g., helicopter) or directly, such as with a backpack sprayer or by “hack-and-squirt” (applying herbicide into spaced cuts in the stem). Selecting an appropriate herbicide depends on the target species and the vegetative distribution on the site. Herbicides should only be applied according to the label and by a licensed professional.

Mechanical and hand treatments (figure 16) are typically conducted following harvest to remove, rearrange, or pile slash, brush, or other debris to create more planting locations by exposing topsoil. Hand-scalping can remove competing vegetation but is difficult and time consuming, and the effects are generally short-lived. Piling slash and debris following a harvest treatment can be an effective approach to create accessible planting spots and reduce fuel loading but can also cause issues such as soil compaction or establishment of undesirable vegetation such as noxious weeds. Further, slash piles need to be burned prior to planting when conditions allow.

Prescribed fire typically includes pile burning following mechanical piling of slash and other debris.

In some cases, burning an entire area (i.e., broadcast burning) can be used, but requires careful planning and must be conducted by qualified professionals.

## Timing and Handling

Reforestation timing depends on the climate, region, and seedling species. Planting is often conducted in the winter or spring. Fall planting is also an option under the appropriate conditions. Seedlings should be dormant when planted. In western Oregon, spring planting generally occurs January through March for conifer species and March and April for hardwood species (Fitzgerald 2008). In eastern Oregon, sites may be inaccessible until after snowmelt, which typically occurs between late March and early May depending on the elevation (Oester et al. 2018). Soil temperature is also an important consideration for planting timing.

Fall planting is generally conducted in October, when root growth is still active but shoots are dormant. Seedlings must be conditioned for fall planting at the nursery to minimize vulnerabilities to environmental stress. Fall precipitation and soil moisture are crucial factors in determining fall planting success (Fitzgerald 2008, Rose and Haase 2006). These factors are relatively unpredictable, which typically makes fall planting less desirable due to higher risk of seedling mortality.

Prior to planting, seedlings must be kept cool, moist, and out of direct sunlight. Seedlings should always be handled gently and kept in a chilled storage area (34 to 40 °F [1.1 to 4.4 °C]) during transport and staging until ready to plant (figure 17). If dormant seedlings must be stored for a period of time before planting, they can be stored in either a cooler or freezer. Seedlings should be stored promptly after lifting. The storage bags or boxes should be sealed to ensure seedling roots stay moist and should be arranged so that at least one surface is exposed to circulating air (Rose and Haase 2006). The ideal temperate range is 29 to 32 °F (-1.7 to 0 °C) for freezer storage and 33 to 34 °F (0.6 to 1.1 °C) for cooler storage. Temperatures below 29 °F (-1.7 °C) increases the risk of potential damage to seedlings (Rose and Haase 2006).

## Site Selection, Spacing, and Protection

The number and spacing of seedlings should match the site conditions, intended stocking, and future forest objectives. In western Oregon, planting density is typically 300 to 435 trees per acre (740 to 1,200 per ha) (table 2) (Fitzgerald 2008). In eastern Oregon, spacing varies due to diversity in site conditions and forest type, species composition, and intended structure. Planting density typically ranges from 135 to 435 trees per acre (333 to 1,074 per ha) (table 2) (Oester et al. 2018).

Tree planting does not have to adhere to a strict grid pattern. Seedlings planted on harsh sites with south-facing slopes or excess sunlight and heat should be planted on microsites. Microsites are selected to

**Figure 16.** Postharvest piling of slash is a first step in site preparation for planting. (Photo by Glenn Ahrens, 2015)

**Figure 17.** After being lifted from the nursery bed and packed in bags, seedlings are kept in cold storage. (Photo by Charley Moyer, Roseburg Forest Products, 2021)

**Table 2.** Planting spacing and approximate corresponding trees per acre vary based on site conditions.

| Spacing (ft) | Trees per acre |
|---|---|
| 8 by 8 | 680 |
| 9 by 9 | 540 |
| 10 by 10 | 435 |
| 11 by 11 | 360 |
| 12 by 12 | 300 |
| 14 by 14 | 225 |
| 16 by 16 | 170 |
| 18 by 18 | 135 |
| 20 by 20 | 110 |

DBH = diameter at breast height.
1 acre = 0.4 ha

**Figure 18.** Microsites are selected to protect seedlings, such as ponderosa pine, from harsh environmental conditions. (Photo from Oester et al., 2018)

protect seedlings from wind, excessive direct sun, frost, and/or animal browse (figure 18) (Oester et al. 2018).

Browse from wildlife or livestock can kill or severely damage planted seedlings. In areas where animal populations are high, protection devices or deterrent products may be needed to reduce seedling damage and mortality. This protection is expensive and time consuming to apply or install and maintain. One of the most common devices is mesh tubing placed around planted seedlings to deter wildlife browsing (figure 19). For rodents, such as gophers or mountain beavers, common control techniques include baiting, repellents, or trapping (Fitzgerald 2008, Oester et al. 2018, Rose and Haase 2006).

## Planting Tools and Techniques

Planting spades, specialized long-bladed shovels, hoedads, and augers are the most common tools used to plant seedlings in Oregon (figure 20). Tool selection depends on the site and the preference of the individual planter. Power augers are less common but can be useful on sites with sandy or pumice soils, or with dense grasses.

Planting holes should be deep enough to cover seedling roots, but not too deep such that the first whorl of seedling branches is buried. Seedlings should be planted upright with all roots covered, and the soil should be firmed around them. It is important to avoid air pockets around roots in the soil, as well as curving or bending roots in the planting hole (figure 21) (Rose and Haase 2006).

## Reforestation in Oregon's Moist Forests

Reforestation in Oregon's moist forests, located west of the Cascade Mountains, accounts for the majority of tree seedlings planted in the State. This is the heart of the coastal Douglas-fir region. Douglas-fir is the primary species planted, and clearcutting followed by replanting is the predominant regeneration approach on most forest industry, as well as some State and private nonindustrial, forest land. Standard industrial practices include harvesting on relatively short rotations (e.g., 30 to 50 years), postharvest site

**Figure 19.** Vexar® tubing around seedlings helps protect from animal browse. (Photo from Oester et al., 2018)

**Figure 20.** Commonly used tree planting tools include long- and short-handled tree planting shovels, hoedads, and tree planting bags. (Photo by Alicia Christiansen, 2020)

preparation, and intensive vegetation control to reduce competitive stress to newly planted seedlings. To this end, herbicide applications may be used both before and after planting, depending on the weed species involved.

Two-year-old bareroot seedlings have been a preferred seedling stock type for decades, but the use of containerized seedlings has increased in recent years to about half of the total. While Douglas-fir is the main species planted on forest industry lands in moist forests (figure 22), other species may be planted in specific situations. For example, western hemlock is sometimes planted in addition to or instead of Douglas-fir on sites in the Coast Range where Swiss needle cast is a threat. A much wider range of species are planted on nonindustrial private forest lands and in ecological restoration projects. While Douglas-fir is still the most commonly used species, landowners

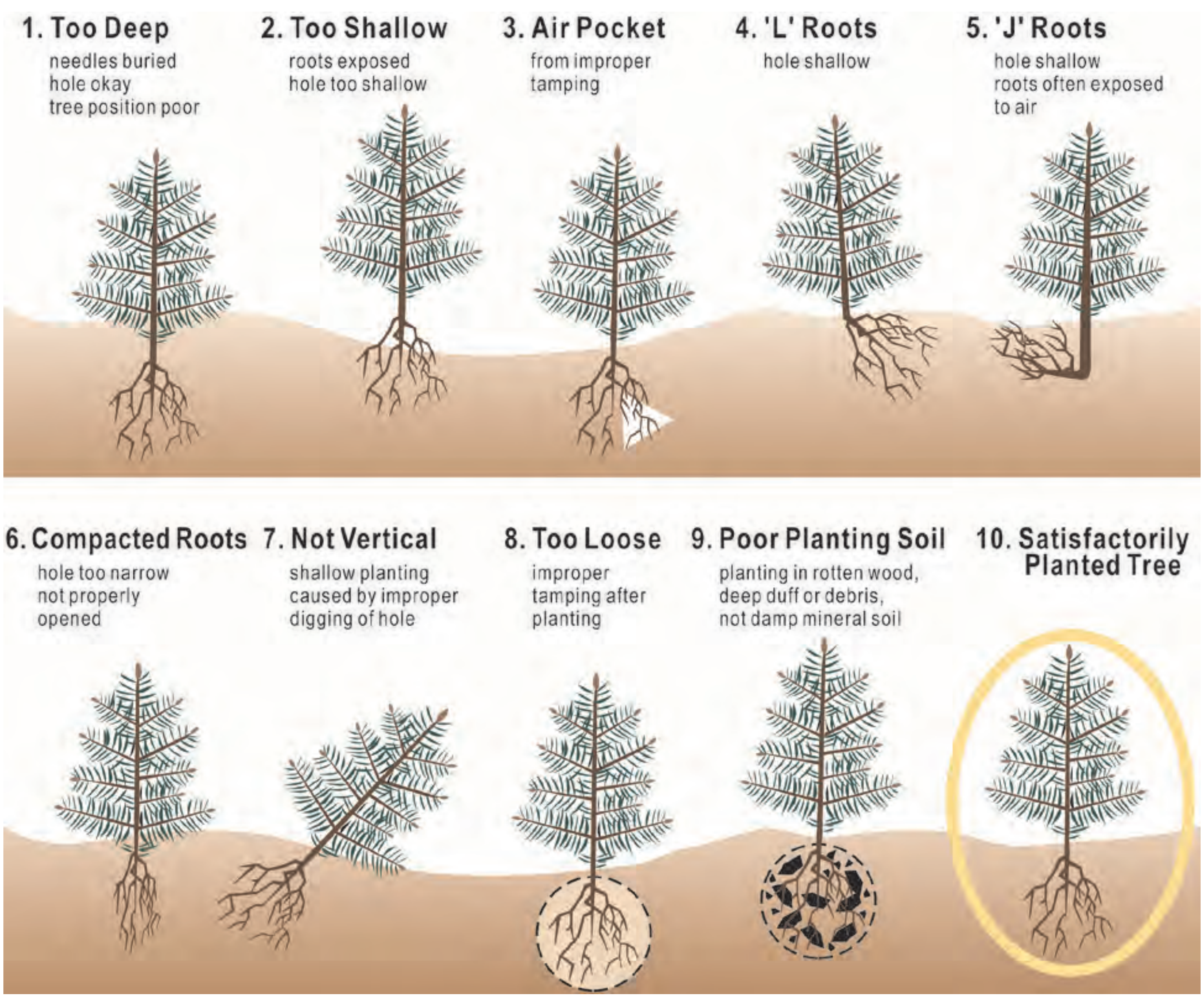


**Figure 21.** There is one proper way, and many improper ways, to plant seedlings. (Adapted from Rose and Haase, 2006)

**Figure 22.** Douglas-fir is the primary species planted on forest industry lands. (Photo by Glenn Ahrens, 2009)

also plant western redcedar, western hemlock, grand fir, and incense cedar. The Willamette Valley variety of ponderosa pine is planted on poorly drained valley sites. Few hardwoods are planted in western Oregon except for red alder on some Coast Range sites. Reforestation practices on nonindustrial private forest lands vary from very intensively managed plantations to interplanting partially harvested stands, though reforestation practices on these lands are generally less intensive than on industry lands.

On Federal lands, enactment of the Northwest Forest Plan in 1994 sharply curtailed timber harvesting through traditional even-aged methods (clearcutting), and the need for reforestation declined as a result. Nonetheless, some harvesting on Federal lands does occur in western Oregon, particularly by the U.S. Bureau of Land Management, and these lands are replanted mostly with Douglas-fir. Control of competing vegetation on Federal forest lands in western Oregon is primarily achieved through mechanical means, such as cutting and grubbing, rather than herbicides. In recent years, large wildfires in western Oregon have greatly increased the need for reforestation on Federal lands. State of Oregon forest lands use reforestation practices that are similar to, but generally less intensive than, industry practices.

## Reforestation in Oregon's Dry Forests

Oregon's dry forests are mainly found in the rain shadow east of the Cascade Mountains, though some dry forests exist in the interior part of southwest Oregon, west of the Cascades. In southwest Oregon, clearcutting and postharvest reforestation with Douglas-fir is still the dominant approach on industry lands, but there is more planting of ponderosa pine than on lands further north. On nonindustrial private lands, thinning and other forms of partial cutting predominate and there is little clearcutting, with owners relying primarily on natural regeneration to restock cutover lands. Reforestation on Federal lands in southwest Oregon is mainly tied to restoration of forests burned in wildfire.

Partial cutting (e.g., fuels reduction and selection harvest) is also more common than clearcutting on private lands in eastern Oregon. Abundant natural regeneration occurs with grand fir, white fir, lodgepole pine, and the interior variety of Douglas-fir (*Pseudotsuga menziesii* var. *glauca*). Interplanting is used to supplement natural regeneration, with ponderosa pine as the most frequently planted species. Interior Douglas-fir is also planted, and there is some planting of western larch in northeast Oregon. Seedling availability can be challenging, particularly for landowners with small forest tracts, and especially following years where wildfires burn across large acreages. Further, planted seedling survival is generally low and is highly dependent on timing, spring moisture, summer temperatures, and competing vegetation control.

**Figure 23.** The Archie Creek Fire burned 131,542 acres (53,233 ha) in late summer 2020. (Photo by Matt Hill, Douglas Timber Operators, 2020)

## Reforestation After Wildfire

Like most western States, Oregon has experienced an increase in the acreage burned in the last few decades. From 2012 to 2021, the largest 20 wildfires burned more than 2.4 million acres of forests across the State. In 2020, five large fires burned more than 800,000 acres (323,748 ha) of forest land in western Oregon (Rasmussen et al. 2021). These fires, known as the 2020 Labor Day Fires, burned at high severity over much of this forest land (figure 23).

Management of postfire forests differs markedly among landowners. Forest industry typically salvages any merchantable fire-killed timber quickly and replants soon thereafter (figure 24). Many nonindustrial owners affected by the 2020 fires lacked the knowledge and resources to reforest after the fires or had higher priority concerns that precluded immediate replanting. On Federal lands, salvage of burned trees is often tied to hazard tree removal or is conducted at a small scale relative to the size of the burned area; reforestation efforts are scaled accordingly. Reforestation after wildfire is hindered for all owners by a lack of seedlings due to the increased demand for postfire planting coupled with normal postharvest planting.

## Tree Planting for Restoration

The 1997 Oregon Plan for Salmon and Watersheds and the associated development of watershed councils throughout the State resulted in a new focus on management of streamside vegetation, including tree planting for riparian restoration. Since then, many riparian tree planting projects have been undertaken around Oregon (figure 25). These projects have been managed by agencies, watershed councils, or other nongovernmental organizations and take place on private and some public lands, often in agricultural or urban settings.

Many restoration projects have been small and have had mixed success with seedling establishment. In some large watersheds, such as the Tualatin and the Rogue, public utilities have funded large-scale planting projects to increase stream shading. These projects are a lower cost alternative to installing a facility to cool municipal wastewater for meeting stream temperature requirements. Red alder, white alder, black cottonwood, willow, bigleaf maple, Oregon ash, and other native hardwoods are the main species planted with a smaller number of conifers and shrubs (figure 26).

Riparian tree-planting projects typically include control of aggressive, nonnative species, such as Armenian

**Figure 24.** A tree planting crew on industrial forest lands planted Douglas-fir seedlings after salvage harvest in the Archie Creek Fire burn area, which burned in the 2020 Labor Day Fires. (Photo by Matt Hill, Douglas Timber Operators, 2021)

**Figure 25.** Drip irrigation and weed mats are used to promote seedling survival during typical hot, dry summers, as was done in this riparian tree planting project near Rogue River, OR. (Photo by Max Bennett, 2013)

blackberry (*Rubus discolor* Weihe & Nees.) and knotweeds (*Polygonum* spp.), through mechanical means, herbicides, or both and may include supplemental irrigation to aid in tree establishment. Working in riparian areas poses numerous challenges ranging from competing vegetation to environmental sensitivities when working around water. Compared with upland reforestation following harvest, riparian projects are usually much more expensive per established tree and tend to have high failure rates when intensive methods are not used (Withrow-Robinson et al. 2011).

Other restoration plantings in Oregon focus on deploying seedlings that are resistant to introduced pathogens such as white pine blister rust. The USDA Forest Service has an ongoing program of screening sugar pine, western white pine, and whitebark pine (*Pinus albicaulis* Engelm.) for rust resistance and producing rust-resistant seedlings for restoration plantings. A similar approach has been used to develop Port-Orford-cedar seedlings that are resistant to *Phytophthora lateralis*, an introduced root disease that has devastated this tree species in forest and ornamental settings.

**Figure 26.** Planted tree and shrub seedlings can be protected by using Vexar® tubes, as was done with this riparian restoration project along Rock Creek in the Archie Creek Fire burn area near Glide, OR. (Photo by Tracy Pope, Streamside Flora LLC, 2022)

### Urban and Community Tree Planting

Most Oregon municipalities seek to maintain or increase urban tree cover for the myriad benefits that such trees provide, such as shading, pollution control, stormwater management, natural beauty, improved health for city residents, and many others. In Oregon, nearly 70 communities are part of the Tree City USA program, and some larger cities and local government entities have urban forestry programs. Tree plantings occur along streets and in parks, greenspaces, and natural areas. Both native and nonnative ornamental trees are planted, depending on the setting. In addition to tree planting by homeowners, local agencies and nongovernmental organizations sponsor tree planting initiatives that provide technical assistance and free or low-cost seedlings to residents and community groups.

## Nurseries and Seedling Production

### Historical Nursery Production and Trends

Private nurseries currently produce the majority of nursery seedlings for reforestation in Oregon. Federal nurseries were historically more important in supporting reforestation on both Federal and non-Federal lands. Federal nursery production declined drastically in the mid-1990s following implementation of the Federal Northwest Forest Plan. The D.L. Phipps Oregon State Forest Nursery focused on providing seedlings for nonindustrial forest owners for more than 50 years, but it was phased out in 2009. Out of 26 forest seedling nurseries listed in the annual catalog *Sources of Native Forest Nursery Seedlings* (Oregon Department of Forestry, Forest Resources Division 2022), there are 23 private, 1 Federal, and 2 State (in Washington) forest seedling nurseries growing trees for landowners in Oregon. Many horticultural tree nurseries produce forest tree seedlings and saplings in Oregon (33 nurseries list Douglas-fir availability), but these are generally larger and higher cost stock types not tailored for reforestation.

The 2008–2009 recession accelerated a trend of reduced seedling production on speculation and increased an emphasis on contract orders, with minimum order sizes of 10,000 to 20,000 seedlings. As in other States, the closure of the State nursery in Oregon and the reduction of seedlings available on speculation reduced seedling availability for nonindustrial owners who have more variable and unpredictable needs.

## Seed Production and Seed Collection

To ensure reliable seed sources for large-scale reforestation of commercial timberland, seed orchards produce about 95 percent of the seed used in Oregon's forest nurseries from genetically improved sources developed by a variety of tree breeding programs (figure 27). Six major tree-breeding cooperatives across Oregon work with three primary seed orchards managed by public agencies: Oregon Department of Forestry (J.E. Schroeder Orchard) and U.S. Bureau of Land Management (Horning and Tyrell Seed Orchards). Some larger private timber companies also have their own breeding programs and seed orchards. The J.E. Schroeder Seed Orchard also maintains the Oregon Seed Bank which provides seed to family forest landowners as needed. The Oregon Seed Bank is sustained with a small percentage of the annual seed crop produced by each cooperator in the seed orchard.

Tree breeding in the Pacific Northwest has long focused on selecting and breeding trees for increased growth and timber production. Climate change has resulted in a growing emphasis to understand genetic aspects of climatic adaptation and tolerance for major tree species across their geographic range. Species vary by their degree of local adaptation. For example, Douglas-fir is rather narrowly adapted with many smaller geographic seed zones, whereas western white pine and western redcedar are more broadly adapted with fewer, smaller seed zones. Research about assisted migration, climate-based seed collection zones, and seed transfer guidelines for adapting to a changing climate is ongoing. As of 2023, however, there are no official changes to seed zones and seed transfer recommendations in Oregon.

Hardwood seedlings account for only about 5 percent of seedling production in Oregon. The increasing focus on ecological restoration and postfire reforestation across the landscape, however, has increased the need for seed collection to support increasing species diversity in reforestation. Strategies proposed for managing forests in a changing climate also call for increasing heterogeneity across the landscape. Seed collection practices, development of new seed orchards, and advances in nursery technology are progressing to meet these evolving needs.

**Figure 27.** Seed germination rates are tested before growing at scale, as was done with this Douglas-fir seed test at the BLM Horning Seed Orchard in Colton, OR. (Photo by Glenn Ahrens, 2019)

## Seedling Production and Nursery Practices

Total seedling production for reforestation in Oregon has increased over the last 10 years, from about 60 million seedlings in 2012 to more than 86 million seedlings in 2021 (figure 28). Forest tree seedling nursery practices in the Pacific Northwest have been well-developed over the last 50 years. The OSU Nursery Technology Cooperative conducted numerous research projects during a period of nearly 30 years. Those projects significantly advanced nursery practices for developing high-quality seedlings matched with outplanting conditions.

Robust bareroot conifer seedlings (1+1 or P+1) with large stem diameter and dense root development have been a popular and successful stock type across a range of outplanting site conditions (figures 29 and 30). In recent years, production of 1-year-old "plug" seedlings (4 to 20 $in^3$ [65 to 327 $cm^3$] container sizes) has surged to meet reforestation demands following wildfires. Estimated production of containerized stock increased from 44 percent of total production in 2012 to 56 percent in 2021 (figure 31). New stock types such as

**Figure 28.** It is common to grow 1+1 stock types in nurseries, as with these second-year Douglas-fir and ponderosa pine bareroot seedlings. (Photo by Glenn Ahrens, 2015)

Ellepots (Ellepot A/S, Denmark) and other fabric/fiber pot container types are currently being evaluated for forest tree nursery production in the Pacific Northwest.

## Nursery System Today and in the Future

Oregon is poised to benefit from major national and international efforts to increase the supply of seedlings for reforestation to restore forests, increase forest health, and capture carbon to mitigate climate change. Multiple Federal, State, and nonprofit entities are focusing on assessing nursery production capacity and increasing production where needed. An additional goal is to expand or tailor nursery capacity to work better for small woodland owners. In 2022, the State of Oregon provided $3 million for increases in private nursery capacity in response to increased demand following the 2020 wildfires, with an emphasis on increasing seedling supply for nonindustrial forest owners.

Development and application of new technology for planting or seeding is in process to meet challenges in postfire situations and other harsh environments. Application of the target seedling concept (Dumroese et al. 2016) to match seedling stock types and specifications to specific outplanting sites is emphasized to ensure resilient seedlings that survive harsh conditions, postfire sites, and increased climate stress. Emerging technologies to aid in reforestation include application of drones for seeding, planting, and reforestation surveys.

## Challenges to Successful Reforestation

Climate change requires increasing attention to methods that improve survival and growth under conditions of heat, drought, and high moisture demand. Methods developed for hot, dry regions are becoming

**Figure 29.** Douglas-fir container stock type examples include (left to right): 4-, 10-, and 20-in$^3$ containers. (Photo from Trobaugh, 2012)

**Figure 30.** Examples of Douglas-fir open bed bareroot seedling stock. From left to right: 2+0, 1+1, and plug+1. (Photo from Trobaugh, 2012)

**Figure 31.** This ponderosa pine plug seedling, grown by Mast Reforestation (Roy, WA), is grown in a fabric pot, a stock type that is currently under development for planting on harsh postfire sites (Photo by Glenn Ahrens, 2023)

more relevant in historically cooler, moister regions. Matching species and seed source to site conditions is more important and challenging than ever. Particularly in southern Oregon, the risk of regeneration failure is high on many postfire sites due to heat, drought, and other harsh environmental conditions. This is where new seedling stock types such as ponderosa pine in fiber containers are being tested.

The 2020 wildfires alone added demand for more than 100 million seedlings In Oregon. Landowners and foresters are challenged by unpredictable events such as fire and climate extremes and situations where reforestation is delayed due to lack of seedlings or contractors to plant them.

Given the challenges outlined above, it is more important than ever to achieve proper planning and execution of every step of the reforestation process, including site preparation, vegetation management, and invasive weed control.

### Insects and Disease

Insect and disease agents interacting with drought and heat are causing significant tree mortality in Oregon (figure 32). Reforestation needs will increase due to insect-infested areas with true firs (fir engraver beetle), pines (ips and mountain pine beetle), Oregon ash (emerald ash borer), and Douglas-fir (flatheaded fir borer). Root diseases and foliar diseases are also affecting large areas. Suitable replacement species need to be chosen that are less susceptible to specific insects or diseases. Providing those species and stock types in a timely fashion following insect or disease outbreaks will place additional demands on nurseries. Breeding to produce genotypes resistant to disease and insects is ongoing for western white pine (white pine blister rust), Port-Orford-cedar (*Phytophthora* root disease), and Douglas-fir (Swiss needle cast).

### Reforestation in Urban Forest Settings

The values and benefits of sustaining and regenerating urban forests are widely acknowledged and addressed in urban tree ordinances and landscape planning. Challenges and considerations for nurseries, arborists, and urban foresters include selection of species and stock types. Large horticultural stock types are the norm in urban settings. An alternative to consider is using smaller reforestation stock to avoid root deformities associated with ball and burlap saplings. Goals for sustaining a component of large native trees (e.g., Douglas-fir, western redcedar, and bigleaf maple) for the urban canopy conflict with common practices of increasing building density, removing large trees, and replacing them with smaller stature cultivars. Urban foresters are faced with finding a balance between benefits and hazards of large native trees within urban infrastructure.

## Growing Forward

Renewed efforts in the forest science and nursery communities are underway to collaboratively address challenges facing reforestation, not only in Oregon, but worldwide (Fargione et al. 2021). It is more important than ever to develop strategies for mitigating effects of climate change using techniques such as diversified plantings, seed source selection, and even new seedling stock types that will

**Figure 32.** Increases in drought- and insect-related tree mortality pose new reforestation needs and challenges, as shown by recent Douglas-fir mortality in southwestern Oregon. (Photo by Chris Adlam, Oregon State University, 2022)

succeed under a range of (likely harsher) conditions into the future. Forest managers have the opportunity to adopt programs and lessons learned to adapt reforestation approaches for hotter, drier summers and increased frequency and severity of disturbances. The forests we plant today will likely look different than those that Oregon's foresters and citizens have been accustomed to for the past century.

### Address Correspondence to—

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# Overview of the U.S. Department of Agriculture, Forest Service's Disease Resistance Screening Center

Kathleen (Katie) McKeever

*Plant Pathologist and Resistance Screening Center Director, U.S. Department of Agriculture, Forest Service, Southern Region Forest Health Protection, Asheville, NC*

## Abstract

The Resistance Screening Center (RSC) in Asheville, NC serves the tree improvement community by receiving progeny seed from breeding programs, exposing seedlings to disease, and evaluating resistance phenotype responses. These data provide early results that may be used to infer performance of field-grown trees in disease-prone areas and can also be used to calculate heritability estimates of resistance traits for future breeding efforts. The RSC is administered within the Forest Health Protection unit of the U.S. Department of Agriculture, Forest Service's State, Private, and Tribal Forestry division, serving any organization engaged in tree seed production, tree improvement, disease resistance, species conservation, restoration, or stewardship activities.

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Efforts in the late 1960s by industry and U.S. Department of Agriculture (USDA), Forest Service researchers to evaluate rust resistance in field-grown pines was aided by the simultaneous development of artificial inoculation techniques and specialized equipment that would help standardize disease loads and rating techniques. With cooperation from North Carolina State University research geneticists, the idea of developing a centralized inoculation facility to perform inoculations and phenotype seedling progeny was generated (Cowling and Young 2013). Creation and administration of the RSC facility was tasked to the USDA Forest Service as a public institution that could offer continuation of long-term resources and is removed from the constraints of commercial enterprise. Because the role of the RSC is to aid in the development of management tools that can be administered on the landscape to mitigate disease, it was placed within the Forest Health Protection unit (formerly Forest Pest Management) of the State, Private, and Tribal Forestry Deputy Area, where applied sciences and service to stakeholders remain the primary foci. Operational screening of pines for rust resistance began in 1973 and today remains an integral part of the RSC's program of work. Successes with screening for fusiform rust resistance led to the development of screening programs for other tree diseases at the RSC, including pitch canker (*Fusarium circinatum* Nirenberg & O'Donnell) and brown spot needle blight (*Lecanosticta acicola* [von Thümen] Sydow) on southern pines; chestnut blight (*Cryphonectria parasitica* [Murrill] M.E.Barr) and root rot (*Phytophthora cinnamomi* Rands) on chestnut (*Castanea* spp.); dogwood anthracnose (*Discula destructiva* (Fr.) Munk ex H. Kern) on dogwood (*Cornus* spp.); and butternut canker (*Sirococcus clavigignenti-juglandacearum* [Nair, Kostichka, & Kuntz] Broders & Boland) on butternut (*Juglans cinerea* L.).

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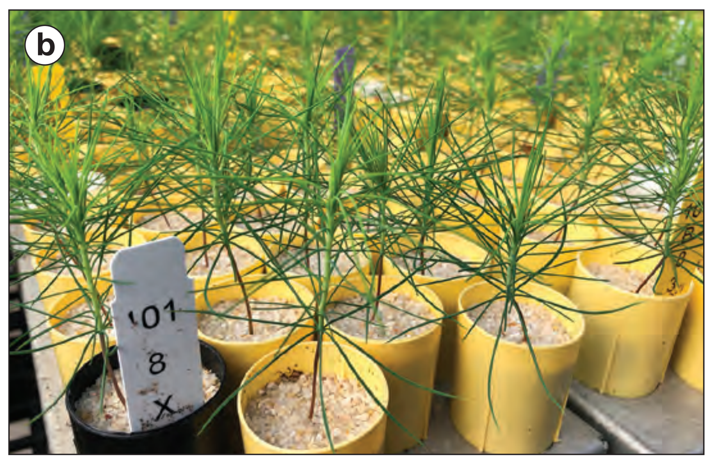


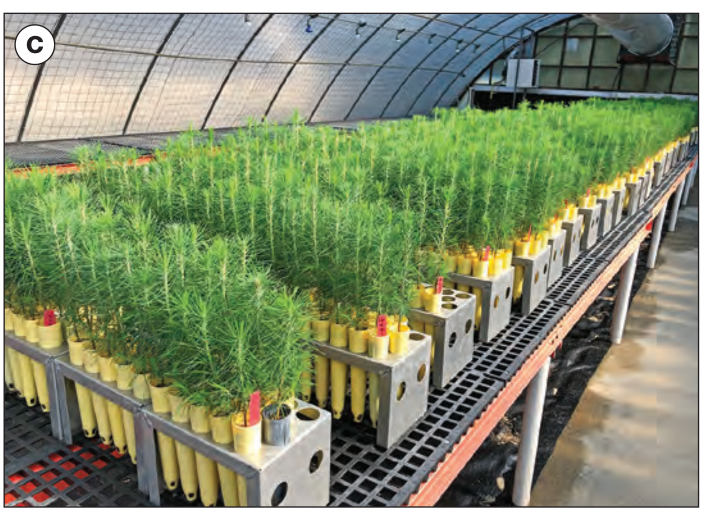
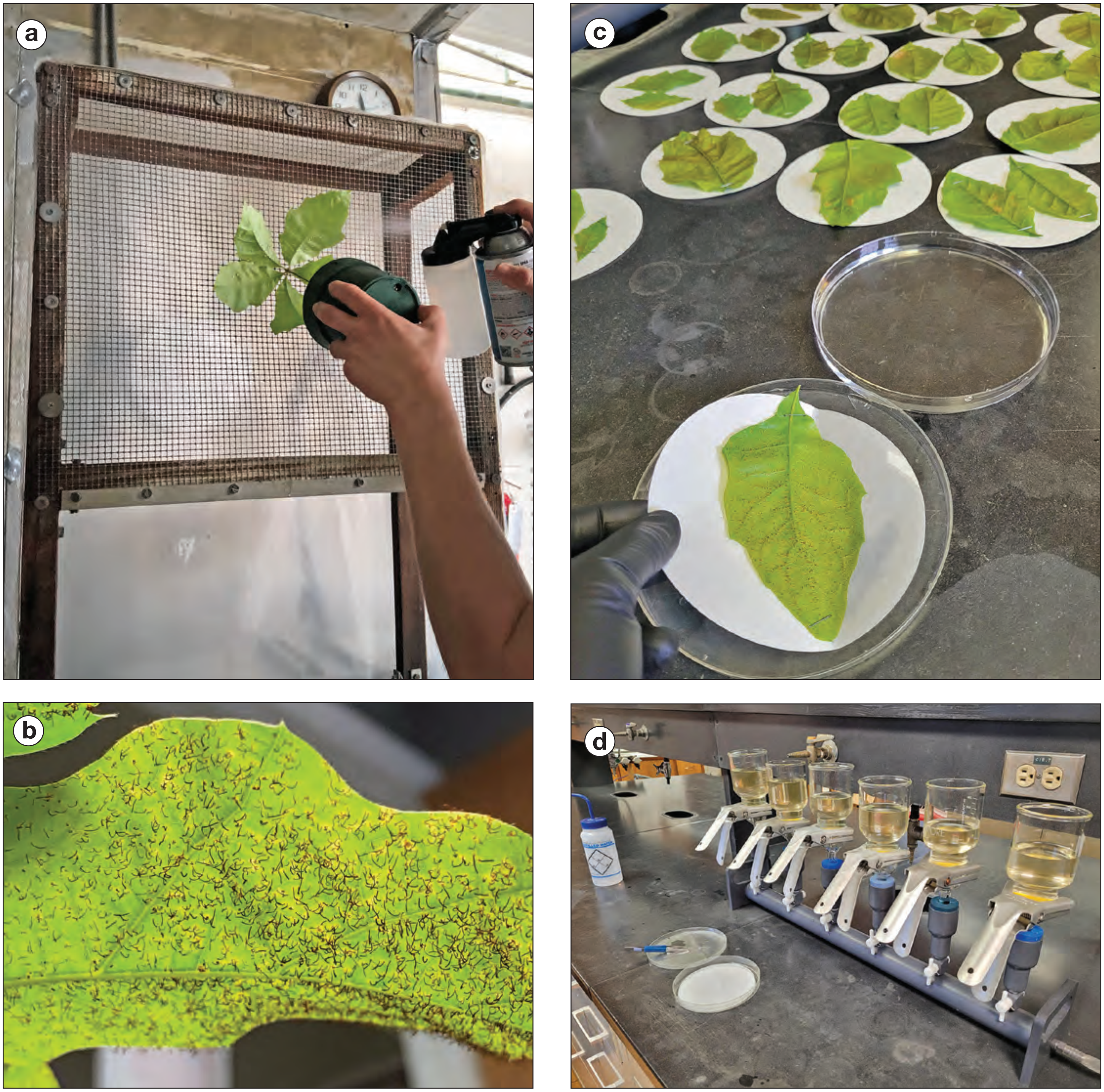




**Figure 1.** Disease resistance screening includes horticultural techniques such as (a) stratification and germination of seed, (b) transplanting germinants to custom soilless media in containers, and (c) seedling maintenance, including watering, fertilizing, and performing pest control measures in a greenhouse setting. (Photos by Katie McKeever, 2022)



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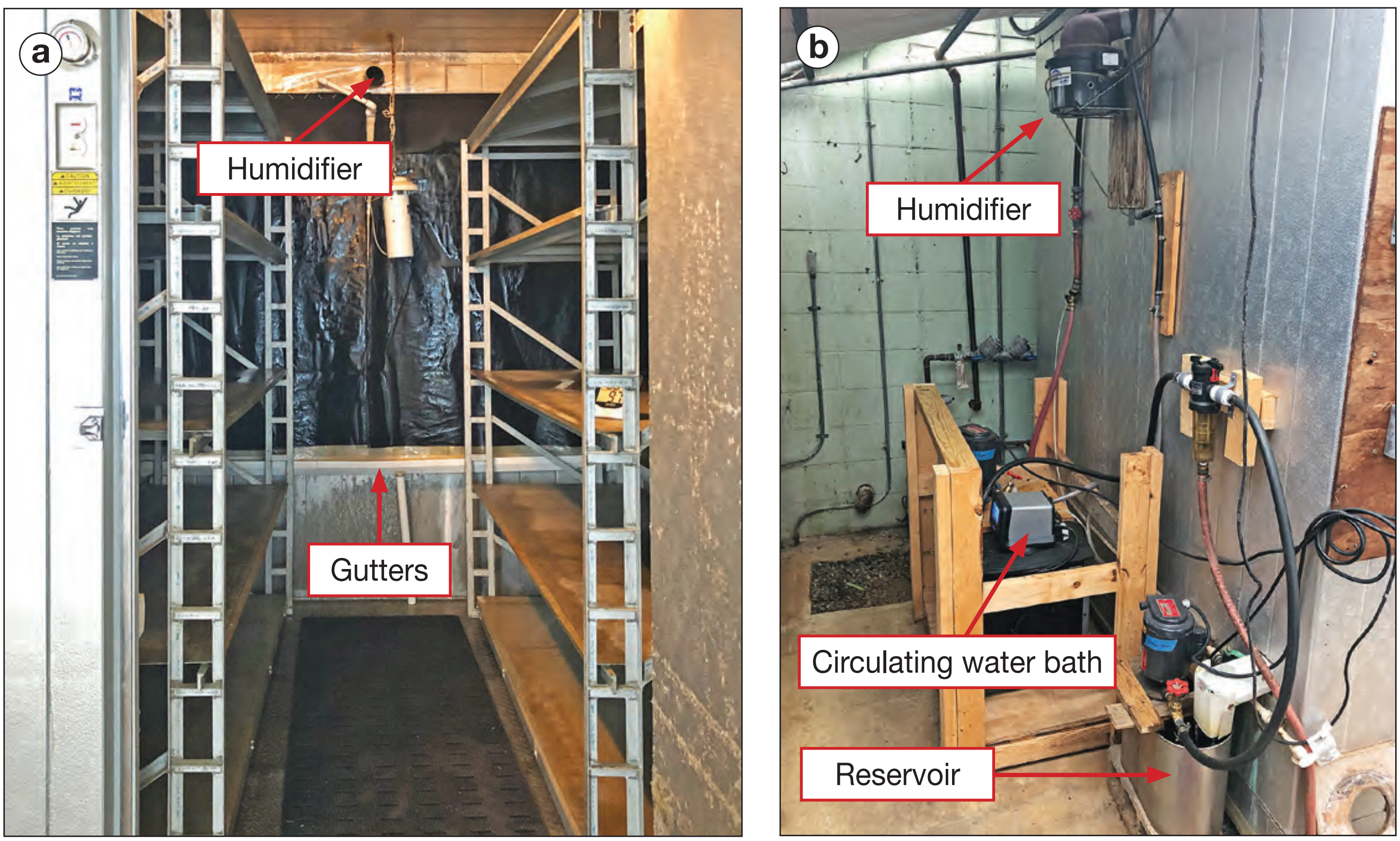


**Figure 4.** (a) Rust-inoculated pine seedlings are incubated for 24 hours on shelves in a dark room that is maintained at 98 percent relative humidity and 20 °C (68 °F). These conditions are favorable to spore germination and infection. (b) Distilled water is tempered in a circulating water bath to 20 °C (68 °F). This water is pumped to a humidifier and dripline that are positioned inside of the chamber. Black curtains are soaked by the dripline inside of the chamber to keep the environment moist. Gutters inside the chamber catch the dripline water and return it to the reservoir where it is pumped back into the circulating water bath in a closed loop system. (Photo by Katie McKeever, 2022)

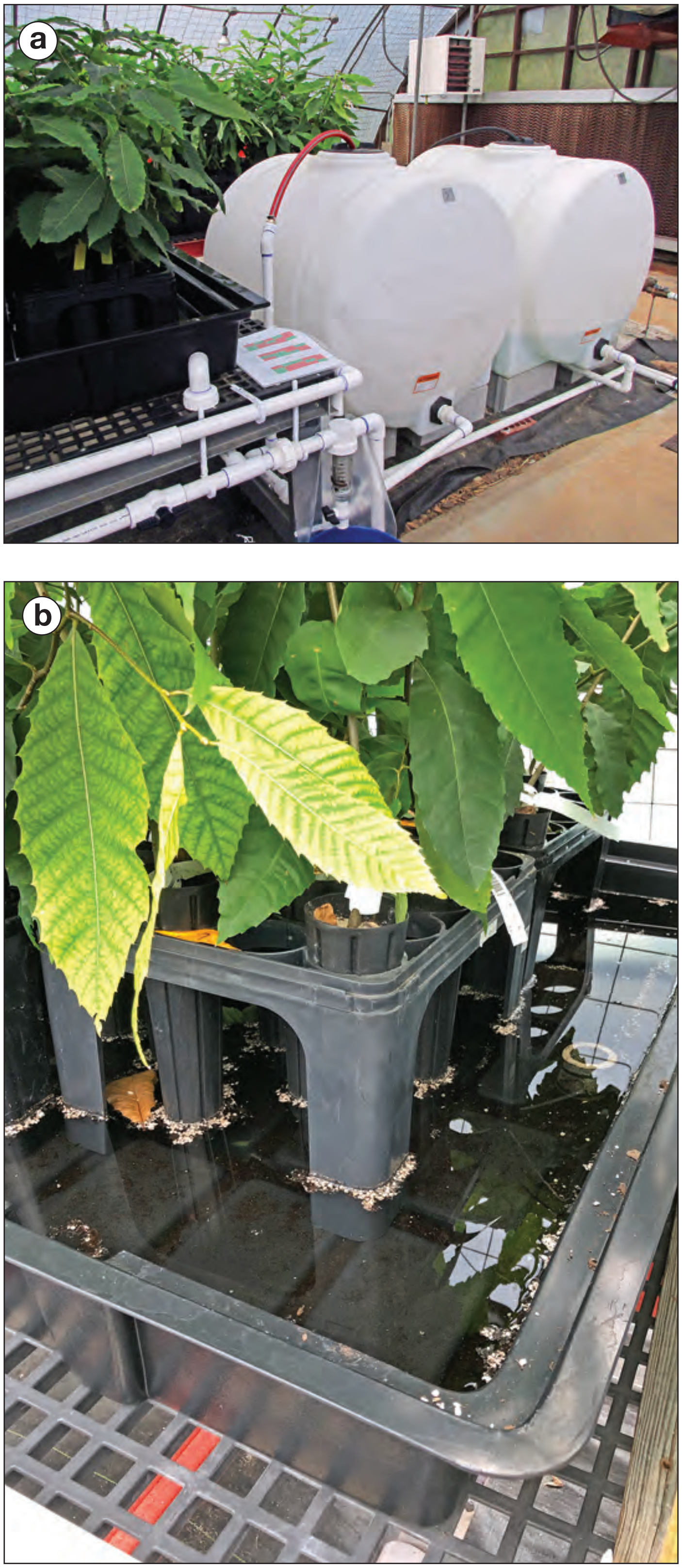


**Figure 5.** (a) The RSC phytophthora root rot screening program uses a subirrigation and water-containment system. Benchtop hydroponics tubs are filled to irrigate chestnut seedlings via capillary action. (b) Tubs are connected to water collection tanks through a system of lines that allow irrigation water to be captured and disinfested prior to release. (Photo (a) by Katie McKeever, 2022 and (b) Sunny Lucas, USDA Forest Service, 2017)

high relative humidity and temperatures favorable to spore germination and infection (figure 4). This brief incubation is a requisite step for achieving disease development before seedlings are moved into the greenhouse for prolonged maintenance and observation.

The RSC partnered with The American Chestnut Foundation to screen blight-resistant hybrid chestnut seedlings for resistance to Phytophthora root rot (PRR). This partnership led to the construction of a specialized subirrigation system that serves to favor conditions for PRR development while also complying with a phytosanitary permit that dictates containment of this nonnative pathogen. In 2016, one of the RSC hoophouses was remodeled to include benchtop hydroponic tubs connected to water collection tanks (figure 5). Trays of seedlings inside the tubs are inoculated with *Phytophthora*-colonized vermiculite incorporated directly into the potting medium of individual seedlings. Seedlings are watered thrice weekly by filling the tubs and moistening the potting medium via capillary action. This technique mimics the flooding events typical in agricultural settings that stress host roots and favor sporulation and dispersal of the pathogen. Draining of the subirrigation water is managed through a series of pumps and cutoff valves to the collection tanks where the water can be disinfected with chlorine bleach prior to release into the environment. These innovative methods of inoculation and pathogen management are hallmarks of the RSC's specialization.

**Figure 6.** Fusiform rust phenotype data on southern pines are collected by recording the frequency of gall incidence within each family. (Photo by Josh Bronson, USDA Forest Service, 2009)

**Figure 7.** Pitch canker phenotype data on southern pines are collected by measuring the length in millimeters of necrotic purple lesions that extend down the stem from the inoculation site. (Photo by Katie McKeever, 2021)

Rust data are collected by recording the frequency of gall incidence within each family (figure 6). Pitch canker assessments have been adapted to include numerical measurements of necrotic lesions to augment binary lesion presence/absence data (figure 7). Chestnuts are evaluated by recording mortality over time and by a visual assessment of root rot severity on surviving seedlings at the conclusion of the trial (figure 8). Screening data are analyzed to provide rankings of family means relative to the known check families allowing inference of relative resistance among progeny populations. Field validation of RSC indices have demonstrated high correlation between artificial inoculation trials and field results, confirming utility of the seedling screening method for tree improvement efforts (Miller and Powers 1983).

## Accomplishments and Future Directions

The RSC has contributed vastly to the understanding and exploitation of host resistance in southern

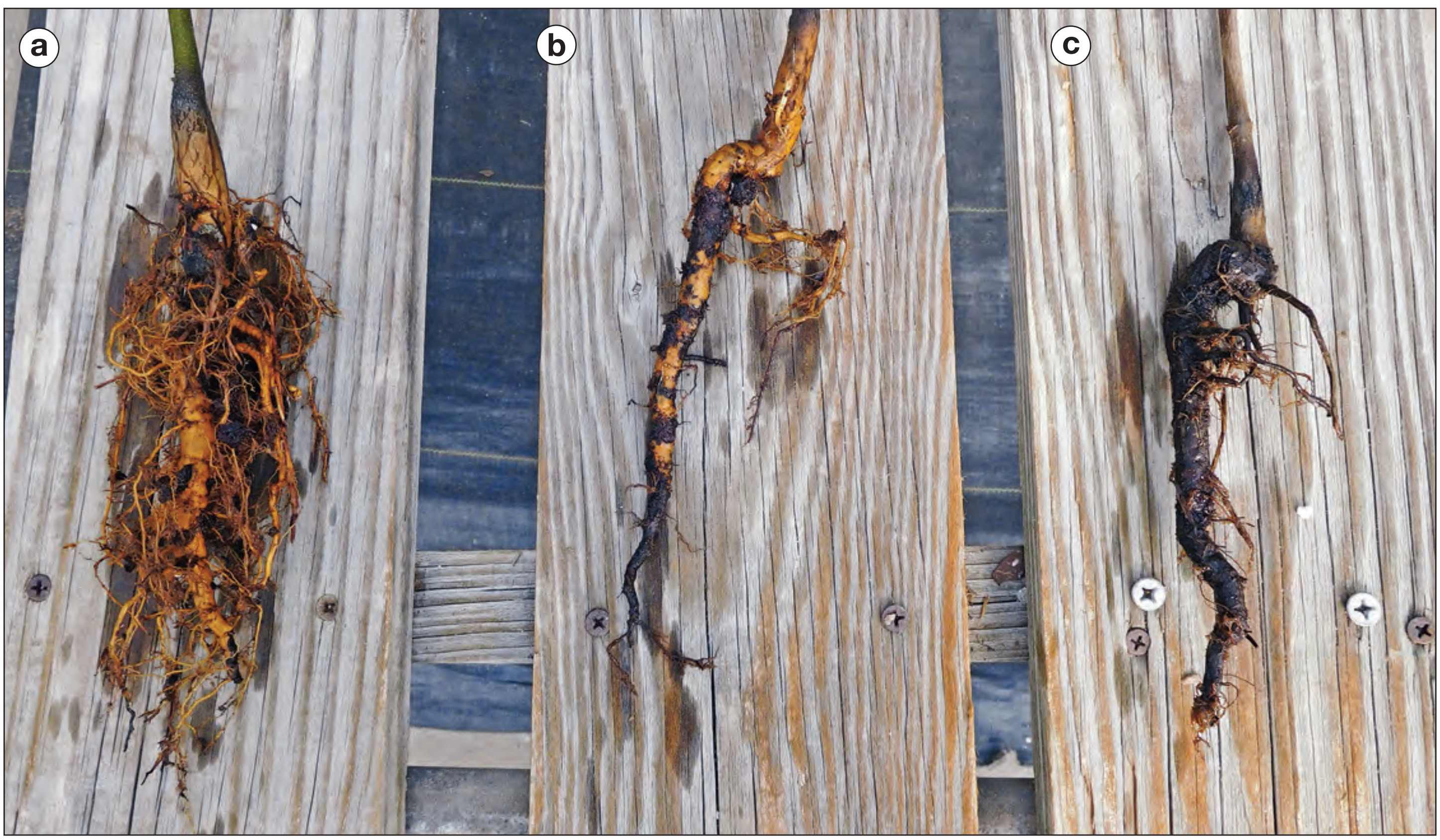


**Figure 8.** Phytophthora root rot on chestnut seedlings is evaluated by visually assessing root rot severity on a 0 to 3 scale at the conclusion of each trial. Seedlings with no root rot are scored as 0. The photos above show a rating of (a) 1 (disease is limited largely to feeder roots with little impact to the taproot), (b) 2 (rot evident on the tap root), and (c) 3 (root system nearly entirely rotted but seedling is still alive). (Photos by Steve Jeffers, Clemson University, 2020)

forests to native diseases. Information derived from screening has been used to structure seed orchards, select breeding parents, aid in clone deployment decisions, quantify heritability of disease resistance, evaluate fungicides for protection of nursery stock, and define molecular control of resistance traits (Cowling and Young 2013). Numerous graduate dissertations have been augmented or enabled through work at the RSC (Cowling and Young 2013). The development of the commercially available anthracnose-resistant "Appalachian Spring" dogwood cultivar (*Cornus florida* L. 'Appalachian Spring') was facilitated through cooperation with the RSC and validated through screening at the facility (Cowling and Young 2013). Selection for PRR-resistance in blight-resistant hybrid chestnut seedlings is aiding in the effort to breed populations with dual resistance to these two damaging diseases, potentially paving the way for restoration of this functionally extinct tree. New projects on the horizon include partnership with the USDA Forest Service Northern Research Station to propagate and screen American elm (*Ulmus americana* L.) seedlings for resistance to Dutch elm disease (*Ophiostoma novo-ulmi* [Fr.] Syd. & P.Syd.) and an effort to develop screening for brown spot needle blight resistance in loblolly pine.

The value of the RSC is substantial, and the impacts are diverse. Emphasis on genetic improvement to combat threats from native and nonnative invasive pests, as well as shifts in host-pathogen dynamics in a changing climate, is a cost-effective and environmentally sound strategy for sustaining forest ecosystem services. Renewed interest in plant breeding and phenotype selection as a vital element of integrated pest management underscores the indispensability of the RSC as a partner in tree improvement efforts for disease resistance in the Southeast United States.

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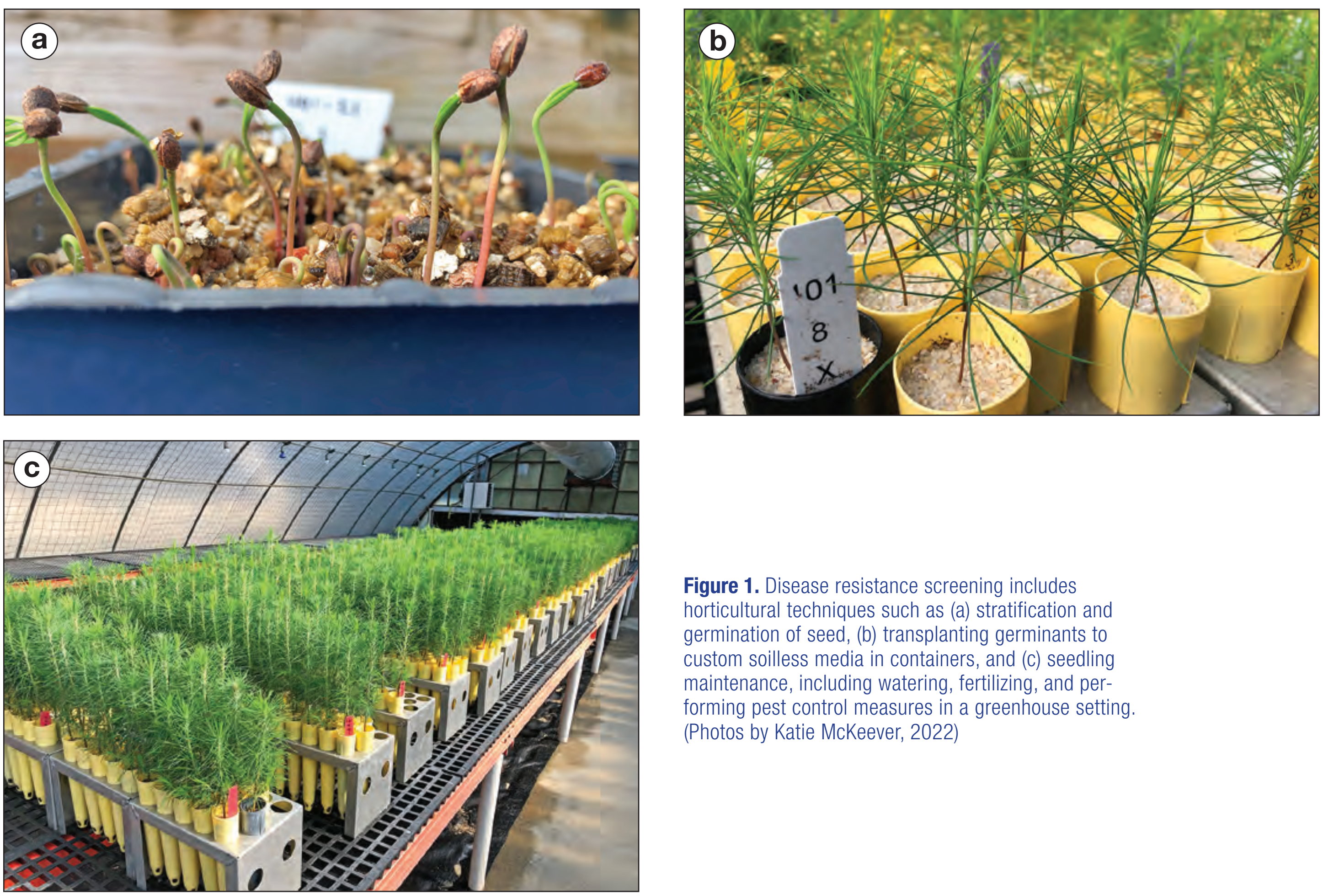


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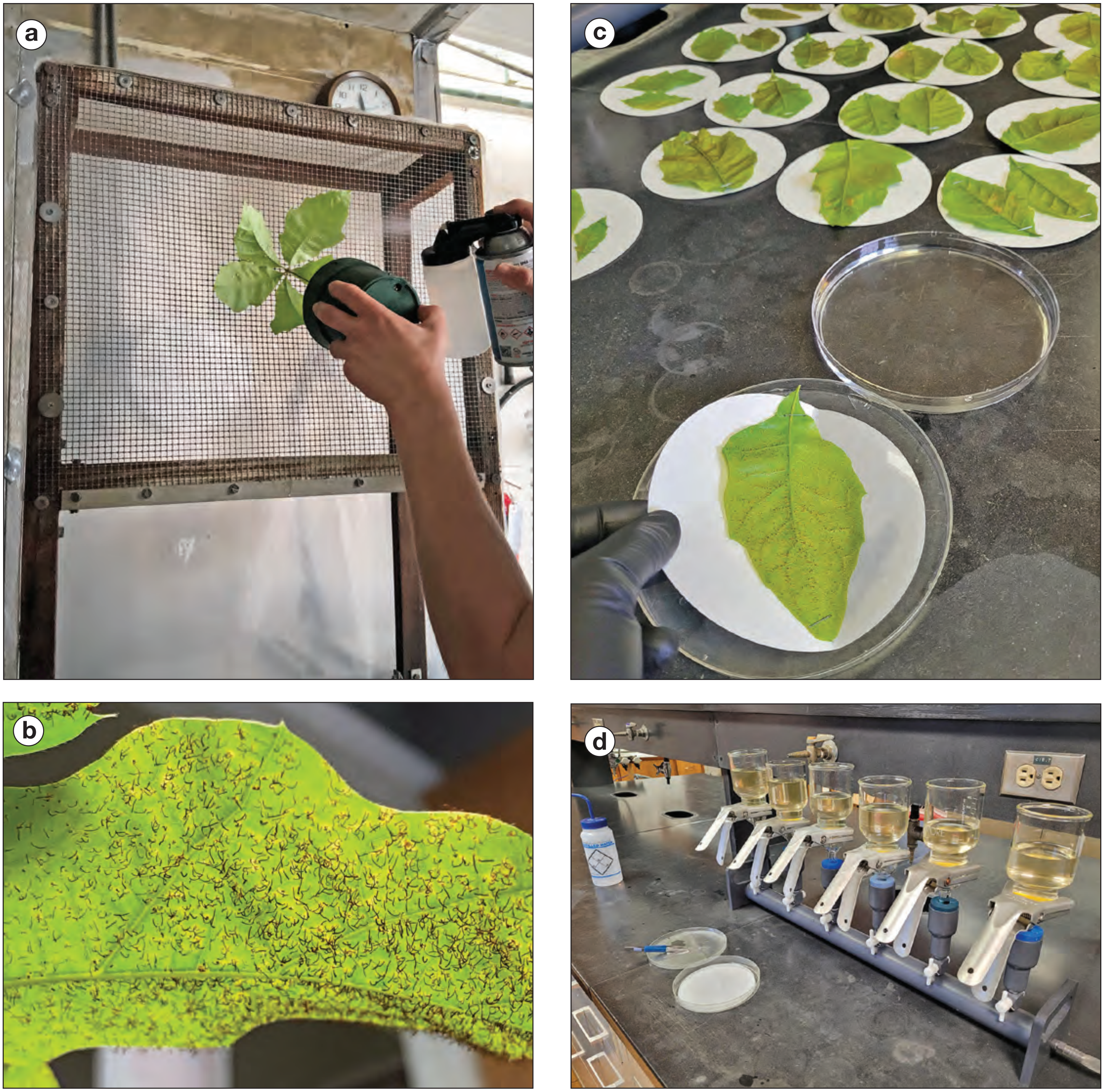


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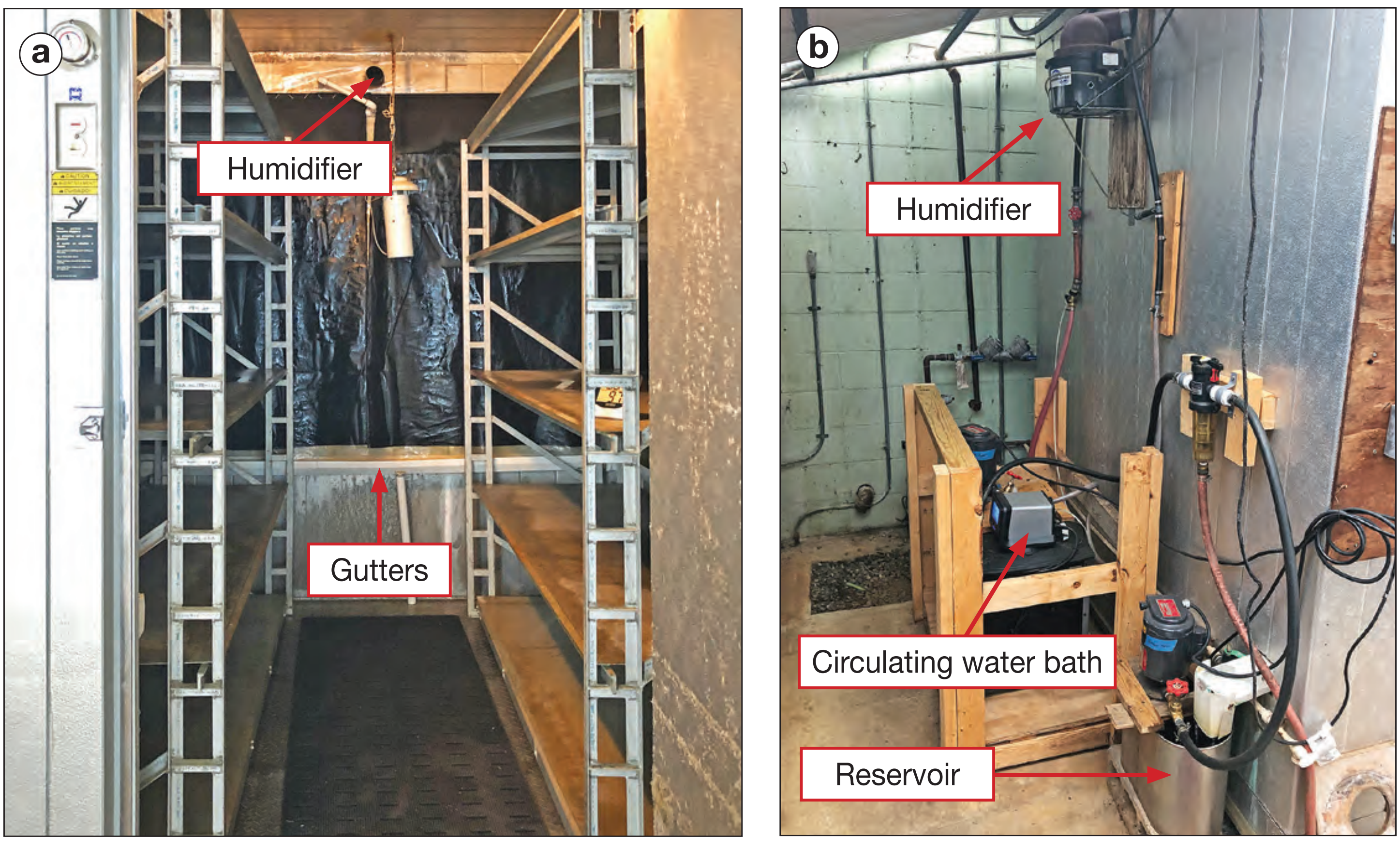


**Figure 4.** (a) Rust-inoculated pine seedlings are incubated for 24 hours on shelves in a dark room that is maintained at 98 percent relative humidity and 20 °C (68 °F). These conditions are favorable to spore germination and infection. (b) Distilled water is tempered in a circulating water bath to 20 °C (68 °F). This water is pumped to a humidifier and dripline that are positioned inside of the chamber. Black curtains are soaked by the dripline inside of the chamber to keep the environment moist. Gutters inside the chamber catch the dripline water and return it to the reservoir where it is pumped back into the circulating water bath in a closed loop system. (Photo by Katie McKeever, 2022)



**Figure 5.** (a) The RSC phytophthora root rot screening program uses a subirrigation and water-containment system. Benchtop hydroponics tubs are filled to irrigate chestnut seedlings via capillary action. (b) Tubs are connected to water collection tanks through a system of lines that allow irrigation water to be captured and disinfested prior to release. (Photo (a) by Katie McKeever, 2022 and (b) Sunny Lucas, USDA Forest Service, 2017)

high relative humidity and temperatures favorable to spore germination and infection (figure 4). This brief incubation is a requisite step for achieving disease development before seedlings are moved into the greenhouse for prolonged maintenance and observation.

The RSC partnered with The American Chestnut Foundation to screen blight-resistant hybrid chestnut seedlings for resistance to Phytophthora root rot (PRR). This partnership led to the construction of a specialized subirrigation system that serves to favor conditions for PRR development while also complying with a phytosanitary permit that dictates containment of this nonnative pathogen. In 2016, one of the RSC hoophouses was remodeled to include benchtop hydroponic tubs connected to water collection tanks (figure 5). Trays of seedlings inside the tubs are inoculated with *Phytophthora*-colonized vermiculite incorporated directly into the potting medium of individual seedlings. Seedlings are watered thrice weekly by filling the tubs and moistening the potting medium via capillary action. This technique mimics the flooding events typical in agricultural settings that stress host roots and favor sporulation and dispersal of the pathogen. Draining of the subirrigation water is managed through a series of pumps and cutoff valves to the collection tanks where the water can be disinfected with chlorine bleach prior to release into the environment. These innovative methods of inoculation and pathogen management are hallmarks of the RSC's specialization.

**Figure 6.** Fusiform rust phenotype data on southern pines are collected by recording the frequency of gall incidence within each family. (Photo by Josh Bronson, USDA Forest Service, 2009)

**Figure 7.** Pitch canker phenotype data on southern pines are collected by measuring the length in millimeters of necrotic purple lesions that extend down the stem from the inoculation site. (Photo by Katie McKeever, 2021)

Rust data are collected by recording the frequency of gall incidence within each family (figure 6). Pitch canker assessments have been adapted to include numerical measurements of necrotic lesions to augment binary lesion presence/absence data (figure 7). Chestnuts are evaluated by recording mortality over time and by a visual assessment of root rot severity on surviving seedlings at the conclusion of the trial (figure 8). Screening data are analyzed to provide rankings of family means relative to the known check families allowing inference of relative resistance among progeny populations. Field validation of RSC indices have demonstrated high correlation between artificial inoculation trials and field results, confirming utility of the seedling screening method for tree improvement efforts (Miller and Powers 1983).

## Accomplishments and Future Directions

The RSC has contributed vastly to the understanding and exploitation of host resistance in southern

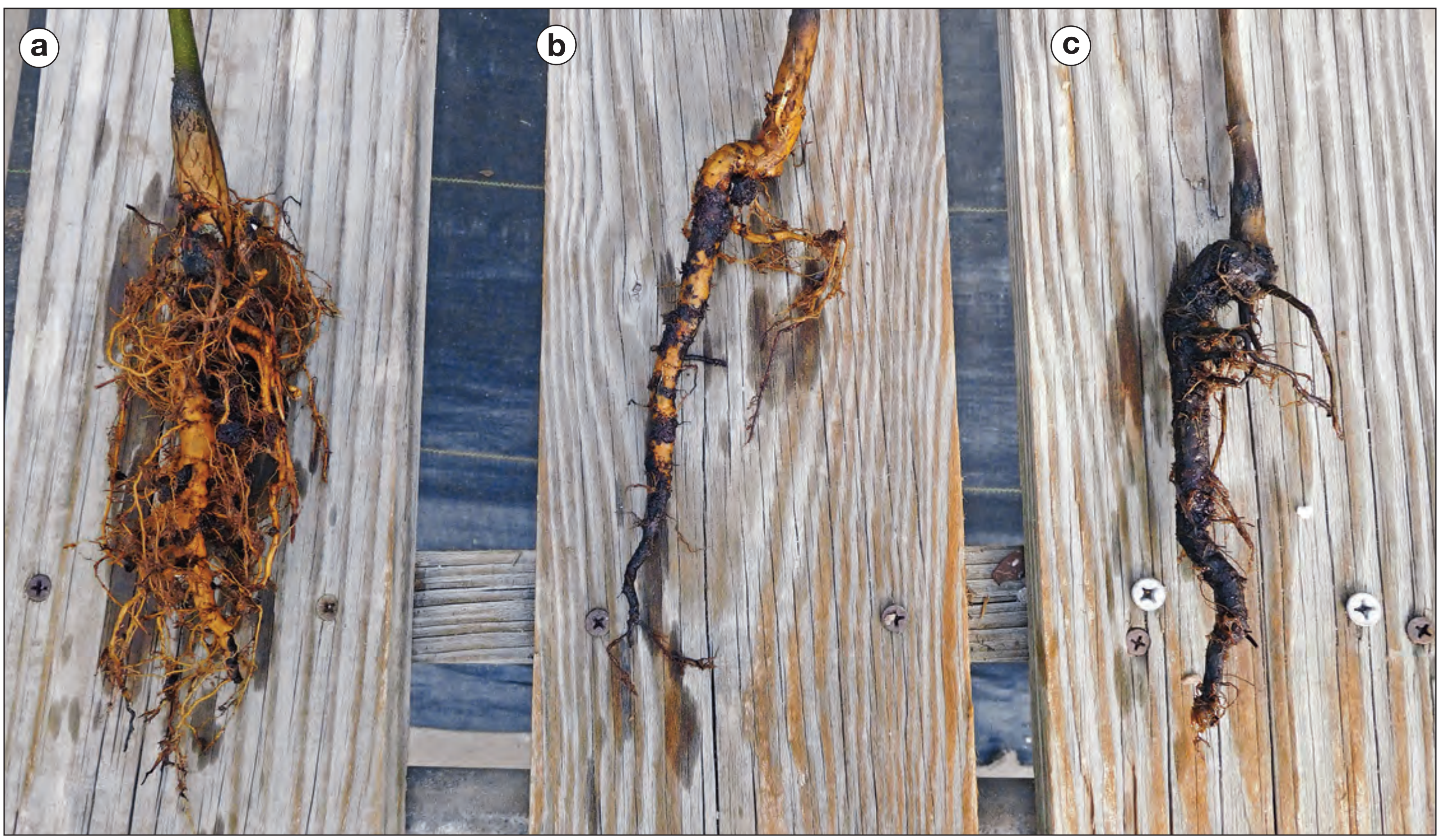


**Figure 8.** Phytophthora root rot on chestnut seedlings is evaluated by visually assessing root rot severity on a 0 to 3 scale at the conclusion of each trial. Seedlings with no root rot are scored as 0. The photos above show a rating of (a) 1 (disease is limited largely to feeder roots with little impact to the taproot), (b) 2 (rot evident on the tap root), and (c) 3 (root system nearly entirely rotted but seedling is still alive). (Photos by Steve Jeffers, Clemson University, 2020)

forests to native diseases. Information derived from screening has been used to structure seed orchards, select breeding parents, aid in clone deployment decisions, quantify heritability of disease resistance, evaluate fungicides for protection of nursery stock, and define molecular control of resistance traits (Cowling and Young 2013). Numerous graduate dissertations have been augmented or enabled through work at the RSC (Cowling and Young 2013). The development of the commercially available anthracnose-resistant "Appalachian Spring" dogwood cultivar (*Cornus florida* L. 'Appalachian Spring') was facilitated through cooperation with the RSC and validated through screening at the facility (Cowling and Young 2013). Selection for PRR-resistance in blight-resistant hybrid chestnut seedlings is aiding in the effort to breed populations with dual resistance to these two damaging diseases, potentially paving the way for restoration of this functionally extinct tree. New projects on the horizon include partnership with the USDA Forest Service Northern Research Station to propagate and screen American elm (*Ulmus americana* L.) seedlings for resistance to Dutch elm disease (*Ophiostoma novo-ulmi* [Fr.] Syd. & P.Syd.) and an effort to develop screening for brown spot needle blight resistance in loblolly pine.

The value of the RSC is substantial, and the impacts are diverse. Emphasis on genetic improvement to combat threats from native and nonnative invasive pests, as well as shifts in host-pathogen dynamics in a changing climate, is a cost-effective and environmentally sound strategy for sustaining forest ecosystem services. Renewed interest in plant breeding and phenotype selection as a vital element of integrated pest management underscores the indispensability of the RSC as a partner in tree improvement efforts for disease resistance in the Southeast United States.

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# Coyote Willow Pole Plantings in Ephemeral Streams of Southwest New Mexico

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## Abstract

Pole plantings are a strategy for stabilizing streambanks along perennially flowing watercourses because the high water table adjacent to these streams allows for successful establishment. In the Southwestern United States, however, such live water is uncommon, though high water flow events during the monsoon season can lead to severe erosion. This study tested strategies at the C Bar Ranch in New Mexico for establishing pole plantings of coyote willow (*Salix exigua* Nutt.) to disrupt waterflow and prevent soil loss during high-flow water events.

## Introduction

Erosion in the Southwestern United States is an ancient problem. Current erosion issues have been caused by a variety of factors, including overgrazing, 17th-century cattle drives, game trails, and topography. At the C Bar Ranch, located about 35 miles southwest of Silver City, NM, we (the Evans family) have been dealing with all of the above.

We settled into the C Bar Ranch in the mid-2000s. The land was homesteaded in approximately 1880. We learned that the former owner had a long and tumultuous history with the U.S. Department of Agriculture (USDA), Forest Service. The ranch had had a long-standing year-round permit for 275 head of cattle through the USDA Forest Service.

When the prior owner passed away in the mid-1970s at age 98, the USDA Forest Service had been waiting for years to reduce the number of cattle on the permit, and approximately 400 head were removed. Thereafter, the ranch passed through several absentee owners. We inherited a permit for 60 head when we moved to the ranch in 2005 and approached the USDA Forest Service about changing the permit to a winter grazing allotment (August through April). The permit was granted. As a result of the planting projects described in this article to stabilize soil, we have since been able to increase our animal units.

## Site Description

The C Bar Ranch is located in the Burro Mountains, near the south end of the Gila National Forest. The land has been historically used as rangeland, with the C Bar Ranch serving as private grazing land and the Gila National Forest serving as a winter grazing range for the registered Angus herd from C Bar Ranch, as well as public recreational land. Firewood is also harvested from this allotment by the public. In addition, hunting permits are sold for mule deer, javelina, and more recently, elk. The elevation range is approximately 5,000 to 7,000 feet. The forest type is primarily pinyon/juniper (defined by the presence of one or more species of pinyon pine [*Pinus* spp.] and juniper [*Juniperus* spp.]). Most of the soils are sandy with volcanic influence.

The climate is temperate. Winter temperatures can dip below 20 °F at night, with an occasional drop below 0 °F. High summer temperatures can range above 90 °F. Records suggest that annual rainfall averages about 16 in, but since moving to the area, we have had more years with precipitation below 10 in than we have had at 16 in or above.

When we first arrived, the ephemeral streambeds had little to no vegetation due to the rapid flow of seasonal floodwaters. The ranch had also been severely overgrazed. The first USDA Forest Service manager we worked with described C Bar Canyon as being so choked with cholla (*Cylindropuntia* spp.) that one could not even ride a horse through it. The Arizona walnut (*Juglans major* [Torr.] A. Heller) and cottonwood (*Populus* spp.) trees had been devoured to their bases, and even the beargrass (*Nolina* spp.) had been decimated. The water table had dropped to the point where all mature trees had died.

The grass species on the ranch are primarily warm-season species, including blue grama (*Bouteloua gracilis* [Willd. ex Kunth] Lag. ex Griffiths), black grama (*Bouteloua eriopoda* [Torr.] Torr.), sideoats grama (*B. curtipendula* [Michx.] Torr.), hairy grama (*B. hirsute* Lag.), Arizona cottontop (*Digitaria californica* [Benth.] Henr.), green sprangletop (*Leptochloa dubia* [Kunth] Nees), sand dropseed (*Sporobolus cryptandrus* Hitchc.), spike dropseed (*S. contractus* Hitchc.), giant sacaton (*S. wrightii* Munro ex Scribn.), and various lovegrass species (*Eragrostis* spp.). Some patches of cool-season grasses are also present, such as Indian ricegrass (*Achnatherum hymenoides* [Roem. & Schult.] Barkworth) and bottlebrush squirrelltail (*Elymus elymoides* [Raf.] Swezey). The shrubs include skunkbush sumac (*Rhus trilobata* Nutt.), manzanita (*Arctostaphylos* spp.), algerita (*Mahonia trifoliolata* [Moric.] Fedde), sotol (*Dasylirion wheeleri* S. Watson), and gray oak (*Quercus grisea* Liebm.). In addition, the site has alligator juniper (*Juniperus deppeana* Steud.), one-seed juniper (*J. monosperma* [Engelm.] Sarg.), cholla, and prickly pear cactus (*Opuntia* spp.). The trees include Goodings willows (*Salix gooddingii* C.R. Ball), coyote willow (*S. exigua* Nutt.), cottonwood, chokecherry (*Prunus virginiana* L.), netleaf hackberry (*Celtis laevigata* Willd. var. *reticulata* [Torr.] L.D. Benson), Arizona walnut, and a grove of Gambel oak (*Quercus gambelii* Nutt.).

### Past and Current Erosion at the Ranch

In 1862, the Homestead Act was passed, offering any adventurous American citizen title to 160 acres of land if they could "prove up," that is, make it habitable within 5 years. This act was drafted by residents of the Eastern United States who did not realize that 160 acres may only support a quarter of a cow in the southwestern part of the country, which was hardly enough for a family to survive.

When the homesteaders came to the area, the canyons were referred to as a "ciénaga," which is a Spanish word for swamp (i.e., wetland). In the monsoon season, the washes would flood bank-to-bank, or canyon wall to canyon wall, thus wiping out the crops planted by the settlers. To control the flow, the settlers built dikes in various places to send the water flow to one side of the canyon or the other, thereby diverting it around their crops. Presumably, they also harvested water at some point. The hand-dug well located at the homestead near the upper end of our part of Walking X Canyon was only 12 to 15 ft deep. The homestead remnants and historical accounts tell us that 2,000 people lived in this small watershed at one point. There was even a school built in the early part of the 20th century. When the homesteaders left, they took their lumber and all the material that held their homes together, but the dikes remained and continued doing exactly what they had been intended to do.

When we moved to C Bar Ranch, the most egregious example of past dike construction was found in Walking X Canyon where remnants of the dikes could be seen, along with huge gorges formed along the rock walls of the canyon. The "farmland" in the middle was full of Russian thistle (*Salsola* spp.). Along the side of the gorge was a vein of black, anaerobic soil. At the upper end of the canyon this vein was about 2 ft below the accumulated flood detritus, and about 1 mile down canyon the vein was about 8 ft below the silt.

As we explored Walking X Canyon over to the neighboring Prevost Ranch, we found that the ciénaga water rose and fell depending on the bedrock structures underlying the washes, portions of which were a beautiful, braided channel. Not far below that was a flood plain filled with Bermuda grass and a massive head cut (an erosional feature in stream geomorphology indicative of unstable and expanding drainage). We monitored that head cut through several flow cycles and observed that it migrated 50 ft up the channel after a single, gentle 2-in rain event.

## Pole-Planting Projects

Dryland restoration can be challenging and require various techniques (Bainbridge 2007). Given the periodic precipitation events on the ranch, we were concerned that further head-cut migration would endanger the entire ciénaga. So, we partnered with the absentee owners of the Prevost Ranch and the U.S. Fish and Wildlife Service's Partners for Wildlife program to reestablish the stream meander and reintroduce native vegetation to the area.

A common vision is to seed native species to reestablish cool-season grasses and other native plants. The reality in our area is, however, that seeding requires


**Figure 1.** Augers were used to create planting holes that were deep enough for the coyote willow poles. (Photo by Erin Evans, 2012)

such precise conditions to succeed that it has a high probability of failing. We have had more success with planting container-grown plants. We have learned that the plants need to be grown in a container that is at least the size of a 4-in wide by 12-in deep Treepot™ (Stuewe and Sons, Inc, Tangent, OR) and must be irrigated after planting until they are established. Thus, our focus was on planting poles based on research showing successes with this approach in New Mexico (Dreesen and Fenchel 2014).

Coyote willow poles were at least 8-ft long and had an approximately 1-in diameter (but not less than 0.75-in or more than 1.25-in) with all the upper growth cut off. We drilled the planting holes 6 ft deep with either a handheld auger or a tractor-mounted auger (figure 1), depending on site accessibility. Planting was done in January and February, before the coyote willow broke bud. We planted the poles as deep as we could get them in the holes, leaving 12 to 15 in aboveground (figure 2).

Our first planting efforts (2010 and 2011) were on the Prevost Ranch with coyote willow poles sourced from a grove in C Bar Canyon. One site was in floodplain soil and the other was in sand. Each planting hole was drilled and had water in the bottom. Because we stuck the poles into wet ground, we anticipated great success. Both sites were adjacent to stream meanders, so wetland conditions appeared to be appropriate for the poles to thrive. Nonetheless, every pole planted in the floodplain soil died. More than half of those planted on the sand bank survived. Still, it was disappointing because we had envisioned poles in the floodplain soil to deflect water back into the meander. We believe the soil may have caused rotting or anaerobic conditions that did not allow proper root development. Based on these results, we concluded that it is critical to backfill with sand rather than soil.

**Figure 2.** Coyote willow poles were planted as deeply as possible, leaving just the top 12 to 15 inches aboveground. (Photos by Erin Evans, 2012)

For the second planting (2012), we revised the planting methods and site selection. We chose two locations near each other that had similar water table heights and waterflow rates during precipitation events. The locations were about 2 miles upstream from the first planting. A neighbor routinely overgrazes their land, resulting in significant flood waters from their side of the fence into our main channel when there is a heavy rain. A rock wall on one side of the canyon deflects the water to the opposite floodplain bank, rapidly eroding the streambank. We planted coyote willow poles along the most vulnerable area of the bank. Pole characteristics and source were the same as the first planting. After a few years, the bank is very stable, the willows are large, and the grass has grown as well (figure 3).

We continued the same planting strategy in an adjacent area in 2013 by planting poles in diagonal rows across the same channel. The first year after planting, the poles were buried by sediment from a flood event. Two years later, however, the poles emerged from the sand and are now armoring the wash adjacent to the previous planting (figure 4).

We have initiated similar experimental plots on the Gila National Forest, several of which have failed due to both elk predation and flooding. One notable success is in a wash with significant erosion potential. In 2017, we began planting at the top of this area which had a shallow sand base sitting on bedrock. Some pole mortality occurred in this upper area. Further downstream were varying depths of bedrock, which influenced where we planted the poles. When we got to an area where we could drill at least 4 ft deep, we planted the poles about 6 ft apart. In every case, there was water in the hole, but we were working in sandy sediments. We fenced this area to prevent elk predation, installing the fence high enough above the wash surface so flood water would not destroy it. After 5 years, the planting is doing well (figure 5).

The pole plantings on the C Bar Ranch and surrounding areas were not placed in riparian areas as

**Figure 3.** Coyote willows planted in 2012 armor a bank at the top of Walking X Canyon. Four years later, erosion has been mitigated, grass has been reestablished on the bank, and the willows have put out numerous suckers. (Photo by Erin Evans, 2016)

**Figure 4.** Diagonal rows were planted adjacent to the armored bank in 2013 but were covered by sediment after a major flood event. Two years later, however, the planted coyote willows had emerged from the sand. (Photo by Erin Evans, 2016)

**Figure 5.** These coyote willow poles were installed on the Gila National Forest in 2017. Three years later, the suckers can be seen along with the protective fencing installed to guard against herbivory. (Photo by Erin Evans, 2020)

usually done for such projects. The conventional technique is to place the bottom end of the pole in persistent groundwater and backfill with soil from the augured hole. At our sites, however, the pole plantings had no adjacent live water. We relied on damp sand to establish the plants, knowing that any water flow would be seasonal, if at all. To prevent losses due to elk herbivory, we used concrete reinforcing wire installed 12- to 18-in above the wash surface, so that any debris carried by floodwater would pass through or deposit in the planting area. While we are using the plantings to slow and distribute the flow of water, a side benefit is the deposition of organic material in the sand washes, which then enables the establishment of grasses and shrubs to further stabilize the streambed.

## Conclusions

The pole-planting method described in this article has proven to be an effective strategy for mitigating erosion in sandy arroyos in the Southwest. Landowners can apply this technique without a large investment in equipment or materials. We plan to continue implementing this process in various target areas throughout our allotment on the Gila National Forest and on the C Bar Ranch private land.

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# The SheetPot: A Low-Cost, Innovative Nursery Container

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## Abstract

The containers in which seedlings are grown play an instrumental role in the economic and practical viability of large- and small-scale tree planting operations. The type of container (pot) can affect the seedling quality when there are issues with root deformation, poor oxygen exchange, and water logging. Issues of planting shock can also emerge depending on how easily seedlings can be removed from the pot. The economic feasibility of planting operations is also affected by container choice and the associated price, packaging volume, and shipping costs. This article describes a new pot system that overcomes these challenges using a rectangular plastic sheet that can be rolled into a cylindrical pot. The sheet can be designed with a diversity of hole configurations to facilitate air pruning, maximize soil oxygenation, and improve irrigation efficiency. The sheets can be stacked into thousands with very small additions to their packaging volume and shipping cost. The research team made the pot and the existing file open-access, including free access to the die cut, with the expectation that this system can be broadly used and improved over time.

## Introduction

The mass planting of trees is a key undertaking to achieve several economic and societal goals from timber production, to cooling cities, to mitigation of greenhouse gases (Griscom et al. 2017). More than 75 percent of the world's land is under direct human pressures (Venter et al. 2016a, 2016b), and approximately 46 percent of trees on Earth have been cut down since the onset of human civilization (Crowther et al. 2015). Currently, approximately 2.5 billion ac (1 billion ha) are available for canopy restoration, are mostly free of conflict for other land uses, and have a potential to store more than 200 gigatonnes of carbon (Bastin et al. 2019). This area of land highlights not only the potential for forest growth, but the latent benefits for mitigating climate change, maintaining biodiversity, and educating society if such a massive endeavor is undertaken by citizens (Mora et al. 2020). While the planning of large-scale tree plantings is by no means simple, one element often emerges as a bottleneck: the container (pot) system.

For container-grown seedling production, the pot is one of the key components determining the feasibility of large-scale plantings. The container needs to provide suitable conditions for growing healthy seedlings to maximize long-term tree survival after planting, while also being affordable as to allow its use at scale. Commercial seedling containers address some, but rarely all, of the potential functional and economic shortcomings of container-grown seedling production. Staff and volunteers with the Carbon Neutrality Challenge developed a new pot system that overcomes numerous challenges associated with seedling containers. The "SheetPot" is made open-source and a mold is freely available; the motivation is to increase its use and inspire future improvements.

## The Project

The SheetPot is one of several developments of a citizen science project called the Carbon Neutrality Challenge. This project aims to mitigate climate change by having individuals estimate their $CO_2$ footprint and then plant enough trees to offset it. Early on, organizers carried out numerous events planting 100 trees at a time with 20 people at most. In the last event, participants planted 10,000 trees with

**Figure 1.** During a large-scale planting operation in November 2021, more than 2,000 volunteers planted 10,000 tree seedlings in 2 hours on the Gunstock Ranch in Hawaii. (Photo by Mike Hinchey, 2021)

2,000 volunteers in 2 hours (figure 1). The project's goals are twofold: first, educate people about how individual emissions add up to create the big problem known as climate change, thereby encouraging people to reduce their carbon footprint; and second, secure the workforce to plant trees at scale. Beyond outreach and education, civic engagement toward the goal of mass tree planting is not trivial. Assuming an average density of 1,000 trees per hectare suggests the need to plant 1 trillion trees in the estimated 1 billion hectares of land available on Earth. Such a mammoth task will require each of the 8 billion humans on the planet to plant about 120 trees during their lifetime, which is a much more manageable undertaking.

## Container (Pot) Challenges

While simple in theory, this project has faced numerous challenges in practice, and a recurring one is the container, or pot, used for growing trees.

### Challenge 1: Removing Seedlings from the Pot

The inexperience of most volunteers at the planting projects, many of whom are children, highlights the need to use pots from which the seedlings can be easily removed and then planted into their hole with the least amount of stress to the seedling; otherwise, planting shock can be considerable. Planting shock can result in wilting, delayed growth, and even mortality. However, removing seedlings from their pots can be challenging, even for the most experienced planters. Depending on the pot's wall angle and how compact the growing medium is, the planter will remove the seedling by squeezing the pot to soften/loosen the soil or by pulling the seedling, both of which add considerable stress to the seedling. When squeezing is exaggerated the soil detaches from the roots, exposing them completely, resulting in a significant shock to the seedling at the critical time of planting. In addition, the angle of the pot's wall affects the pot's volume and its ability to be stacked, both of which influence shipping costs, which can be significant for remote places.

### Challenge 2: Spiraled Roots

Spiraled roots occur when the seedling's roots reach the sides and bottom of the pot. If the container has smooth sides, such as polybags (Haase et al. 2021) and many types of commercially available plastic pots, the roots will spiral. After planting, seedlings with this deformed root system will struggle to maximize water and nutrient uptake and can have long-term issues with growth and stability.

### Challenge 3: Water Logging

Waterlogging, or perched water table, results from the interaction among water, growing medium, and pot dimensions. Shorter containers tend to have a greater proportion of saturated medium than taller containers (Landis et al. 2014). Waterlogging occurs due to the interacting forces of gravity pulling the water downward, cohesion sticking the water and substrate together, and capillarity pulling the water upward. Where those three forces even up, the water gets "perched." Waterlogging causes the saturated layer to be constantly submerged in water, which makes the seedling prone to disease, causes poor soil oxygenation, and reduces nutrient uptake. Some tree species are particularly sensitive to having "wet feet" and fail to grow any roots in the waterlogged parts of the growing medium.

### Challenge 4: Root and Shoot Mass

When planting seedlings in harsh landscapes or in situations where maintenance will be limited to none, it is critical that the seedlings have a large root mass so they can quickly acquire nutrients and water. Ideally, seedlings should also be tall enough to gain a competitive advantage against weeds. A target shoot-to-root ratio should be selected based on expected site conditions. For example, seedlings with a smaller shoot-to-root ratio perform better on droughty sites compared with those that have larger shoot-to-root ratios. Container size, along with nursery culturing regimes, dictate the final seedling size. Another critical consideration about the pot size (and resulting seedling size) is the space they occupy at the nursery, with smaller containers being more desirable as many more seedlings can be produced in the same nursery space. This calls for some flexibility in pot dimensions to maximize the tradeoff between quantity and quality of seedlings.

### Challenge 5: Soil Oxygenation

Oxygen in the soil is critical to seedling nutrient uptake and can be strongly affected by the pot. No oxygen exchange occurs in areas of the pot covered by solid plastic. Thus, oxygen exchange only occurs over the exposed area of the substrate at the top of the pot and at any holes at the bottom or wall of the pot. If the pot is tall, reduced oxygen levels can occur towards the middle of the pot, especially if the growing medium is poorly drained. Such a condition can cause problems of anoxia, evidenced by a rotten smell in the substrate. Reduced oxygen exchange and methane production becomes particularly problematic when over-irrigation occurs.

### Challenge 6: Production and Shipping Costs

Polybags or simple plastic pots are used in many parts of the world because they are inexpensive to purchase and ship, but these containers are prone to all of the challenges described in the previous sections (Haase et al. 2021). Several containers have been designed to address the challenges and are commercially available, but unfortunately, they are too expensive for many volunteer programs and for seedling production programs in areas of the world with limited resources. Our volunteers refer to those containers as "Rolls Royce pots" because, as the cars, these sophisticated pots would be nice to have, but unaffordable to buy. Another major cost is shipping. For remote locations, the cost of shipping containers can often be higher than the price of the containers themselves. Pots that do not stack well or need bulky trays require a large volume of packaging and are especially costly to ship.

## Solution: The SheetPot

Our (the Carbon Neutrality Challenge staff and volunteers) motivation to develop a new pot system emerged from the fact that most commercially available pots were prone to the technical and practical shortcomings outlined above and resulted in significant tree mortality after our planting events. Also, we were unable to afford "Rolls Royce pots."

The SheetPot described here is the latest in a series of prototypes developed to address the container challenges, while remaining affordable in terms of the product itself and its shipping. The following sections summarize the evolution of this pot system to highlight ideas that were tested and to motivate future innovations.

### Prototype: The Paper Pot

Interestingly, the origins of our work to design a better pot system stemmed from an error by an inexperienced

**Figure 2.** The motivation for developing the SheetPot originated following the observation that a volunteer erroneously planted a seedling with the plastic pot. Thus, the original idea was that seedling pots could be planted directly into the ground to lessen planting shock. (Photo by Audrey Rollo, 2015)

volunteer who planted a seedling with its plastic pot (figure 2). Perhaps this person was frustrated by being unable to remove the seedling and decided to plant it with the pot. Regardless, this incident made us realize that a major stress to the seedlings could be avoided if the seedlings were planted with their pot. A quick search into this option revealed numerous options, including the use of paper pots. We used existing concepts like the Zipset™ Plant Bands (Stuewe and Sons, Inc., Tangent, OR) and developed several designs using a diversity of paper materials with natural and plastic coatings (figure 3). We also used rolls of newspaper in a custom-made tray. Paper pots were very affordable and reduced planting shock considerably but were problematic because the paper material decomposed in a few weeks (figure 4). The use of different coating materials on the paper lengthened the longevity of the pots, but water eventually eroded the paper, causing the medium to break apart and expose the roots. An additional problem was that paper pots cannot be placed side by side as they stick to each other. We developed a tray to keep the paper

**Figure 3.** Different types of paper pots were tested to determine their feasibility as a low-cost container for producing quality seedlings on a large scale. (Photo by Audrey Rollo, 2022)

**Figure 4.** During evaluation of paper pots, the problem was noted that the pots stick to each other upon contact. (Photo by Audrey Rollo, 2022)

pots separated and expected it could increase the pots' longevity, but it did not. We noted, however, that with certain fibrous substrates, there was no need for the pots to have a bottom.

## Prototype: The Net Pot

The discovery that we did not need a bottom in the pot led us to test different types of nets as pots. Basically, we rolled a sheet of mesh into a cylinder and placed it in a custom-made tray to create a seedling container. Originally, we used plastic chicken mesh, but the holes were too large, and the soil slowly eroded from the pot (figure 5). We then tested mosquito nets, which worked much better (figure 6). This system created direct air-soil interaction that maximized oxygen exchange, allowed for air-pruned roots, eliminated water logging, and allowed for easy removal by unrolling the nets. These net pots were very effective at avoiding container challenges mentioned in previous sections, but required a tall, bulky tray to hold them. Additionally, the mesh could be reused, but washing them for sterilization was time consuming.

## Final Product: The SheetPot

After trials with the net pot, we knew that we did not need a bottom for the pots and that the rolled materials

**Figure 5.** A pot prototype based on chicken fencing was tested to determine its feasibility as an easy-to-use and low-cost container. (Photo by Audrey Rollo, 2022)

**Figure 6.** The pot system based on chicken fencing (figure 5) was redesigned using mosquito net during the process to develop a low-cost container for production of high-quality seedlings. (Photo by Audrey Rollo, 2022)

(paper or mesh) could be used to hold the growing medium. But, we still needed to overcome the need for a bulky tray and for being able to easily reuse the pots. What was needed was a rigid material, such that the pot could maintain its shape and only require a smaller tray. The idea eventually emerged for a plastic sheet with locking tabs that hold the sheet in a rolled position, thereby only necessitating a relatively small tray (figure 7). The sheets can be perforated with holes in any configuration to control the speed at which soil dries, avoid waterlogging, and allow for oxygenation. We used 0.3-in (0.8-cm) diameter holes spaced 0.5 in (1.3 cm) apart. Each row of holes is offset by 0.25 in (0.64 cm) (figure 8). We found that this spacing and configuration provided enough aeration to facilitate air-pruning of the roots. During irrigation, each drop of water rolling down the pot's wall has 15 chances to intersect a hole and thus increase irrigation efficiency.

The sheet can be built with a variety of plastic materials, thicknesses, and UV protection. The sheet can be made of any color, but we chose white to reduce pest camouflage. The sheet is made of polypropylene, which can be mixed with UV preservatives to increase the longevity. Other materials, such as polyvinyl chloride, could also be suitable. Our current sheet is 0.02 in (0.5 mm) thick, 15-in (38 cm) tall, and 4-in (10-cm) diameter. The current cost is $0.30 per sheet; using thinner and shorter sheets can reduce the cost proportionally. We have tested sheets as thin as 0.1 mm and found they performed just as well while reducing cost and shipping volume fivefold. The sheets can be modified to varying heights by cutting the sheet or using custom, affordable die cuts. The only constraint is the pot diameter which was set to fit a custom-made tray. We chose a 4-in (10-cm) diameter to match the size of the drill bit of the popular BT 45 earth auger (STIHL Inc., Virginia Beach, VA). Seedlings produced in our pot can be put directly into these holes without any additional soil and with minimal stress to the roots. The sheet can be designed in other diameters, provided a holding tray is available. We recommend elevating the trays to ensure air pruning at the bottom and to avoid spiraling roots. Further improvement may include a different locking mechanism or no locking mechanism at all.

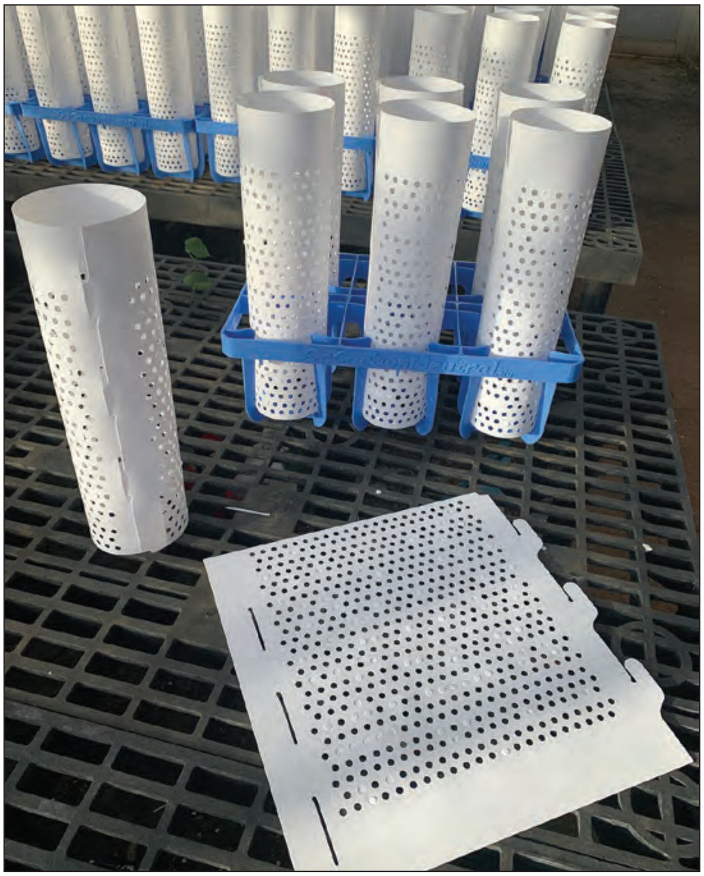

**Figure 7.** Using the SheetPot overcomes many challenges associated with seedling production. (Photo by Audrey Rollo, 2022)

**Figure 8.** The SheetPot has proven to be a successful design for production of high-quality seedlings in a low-cost pot and is available open-source for wide use. (Photo by Audrey Rollo, 2022)

In addition to being able to grow a quality seedling, the SheetPot can be stacked flat for shipping then assembled onsite, thereby reducing bulky packaging and shipping costs. Also, the plastic is durable enough that it can be sanitized and reused multiple times, thereby further reducing long-term costs and avoiding the use of single-use plastics.

## Closing Remarks

Currently, there is a large global opportunity to significantly increase forest coverage of our planet. Since the onset of human civilization, people have removed nearly half of the trees that ever existed, yet there is an obvious opportunity to replant many deforested areas. While there is an eagerness to plant trees, we have learned that there are numerous challenges to such a task. Restoring the world's tree canopy requires a concerted global social effort, development of tools, and improvement of processes. We decided to make our SheetPot design open-source so it can be used by anyone without limitation. Additional information, photos, videos, and files for the pot are publicly available at: https://github.com/Camilo-Mora/MorasPot/tree/main. A discussion forum is also available, which we hope can become a hub for ideas that can help the continued evolution of the Sheetpot.

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# Shortleaf Pine: Guidance for Seed Transfer Within the Eastern United States

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## Abstract

Shortleaf pine (*Pinus echinata* Mill.) is a shade-intolerant conifer tree native to forests across the Eastern United States, extending from east Texas to New Jersey. Shortleaf pine has declined sharply in abundance during the last several decades due to species conversion, reduced fire frequency, and competition with encroaching broadleaf trees. Genetic diversity of the species is high due to high seed dispersal and long-distance pollen dispersals maintaining low population structure across the species' range. Shortleaf pine can hybridize with loblolly pine (*P. taeda* L.), which could increase if climatic shifts begin to synchronize pollen dispersal and receptivity of the two species. Fire is an important component of shortleaf pine ecosystems and helps to reduce hardwood and pine competition, including loblolly pine hybrids. Local seed sources are generally best in far northern and southern areas of the species' range. In central and northern areas, seed transfer from sites that are warmer by 7 and 5 °F (3.9 and 2.8 °C) average annual minimum temperature, respectively, may have increased growth relative to local sources. Shortleaf pine is highly susceptible to southern pine beetle but is relatively resistant to fusiform rust disease. Shortleaf pine is likely to persist, or expand northward, in the future because of its high tolerance to drought and fire.

## Introduction

Shortleaf pine (*Pinus echinata* Mill.) is a long-lived, shade-intolerant conifer that grows on relatively dry, infertile sites across the Southern United States. It has the largest range of any southern pine, growing across 22 States and as far north as New York's Long Island (Lawson 1990). Shortleaf pine may occur as pure stands (figure 1) or as a component of pine/oak and loblolly/shortleaf pine forests (Lawson 1990), driven in large part by past disturbance regimes (Guyette et al. 2007). Sharp declines in abundance over the last 50 years are attributed to a combination of overharvesting, fire suppression, and stand replacement by loblolly pine (*P. taeda* L.), which is a preferred commercial species (McWilliams et al. 1986). Shortleaf pine wood is relatively dense and is used for building construction, railroad ties, and plywood (Alden 1997). In pine/oak stands, shortleaf pine is sympatric with black oak (*Quercus velutina* Lam.), white oak (*Quercus alba* L.), and hickory (*Carya* spp.), but it may be out competed in the absence of disturbances that increase available light (Stambaugh et al. 2002) or bare mineral soil for natural regeneration (Guyette et al. 2007). Efforts to reduce competition are often required if hardwoods are dominant in the understory (figure 2). Low recruitment, along with the decline in abundance, has led to increased restoration and tree planting efforts (figure 3) such as the Shortleaf Pine Initiative (https://shortleafpine.org). Compared with other southern pines, shortleaf pine is slower growing in its early years, but is relatively cold tolerant and fusiform rust resistant. Cold injury may appear as winter burn on needles and frost heave (Pickens and Crate 2018).

Shortleaf pine is moderately fire tolerant because of its thick, platy bark and its ability to resprout after light- to moderate-intensity fires (figure 4). Mature stands can tolerate exceptionally hot fires if crowns are not burned (figure 5). The presence of a basal crook at the root collar protects dormant buds during fires, allowing the species to resprout (Bradley et al. 2016, Lilly et al. 2012, Little and Somes 1956, Stewart et

**Figure 1.** Shortleaf pine is commonly associated with oaks (*Quercus* spp.), since both require high light environments and similar temperature and moisture regimes. (Photo by C. Pike, 2019)

**Figure 2.** Competition, especially from hardwoods, should be managed to facilitate regeneration of shortleaf pine, which is otherwise shade intolerant. In this photo, goats were brought in to help control competing vegetation from hardwood trees and shrubs. (Photo by C. Pike, 2019)


**Figure 3.** Restoration with tree planting is necessary to restore shortleaf pine in stands that have converted to hardwoods or other vegetation. Trees growing in this container will be outplanted in a few months. (Photo by C. Pike, 2018)

**Figure 4.** The lower boles of shortleaf pine trees have very thick, platy bark that can survive light- to moderate-intensity wildfires. (Photo by C. Pike, 2019)

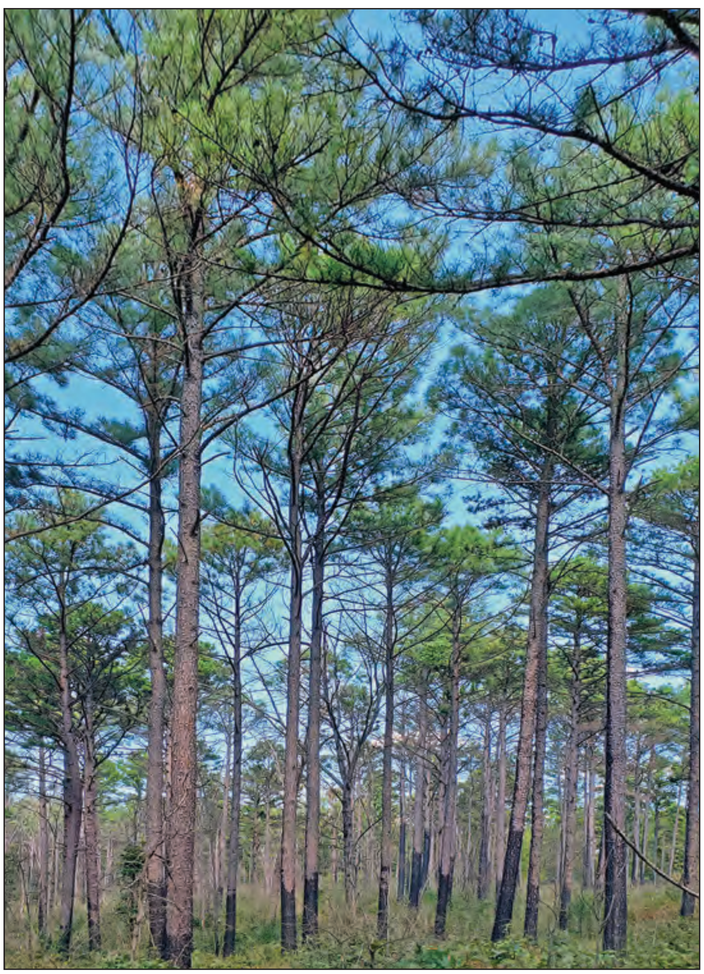

**Figure 5.** This stand sustained an extremely hot fire that destroyed most of the understory, while the mature shortleaf pines survived. (Photo by C. Pike, 2019)

**Figure 6.** Shortleaf pine seedlings form a basal crook that is an adaptive trait to protect against fire damage. (Photo courtesy of Southern Research Extension Forestry)

al. 2015) (figure 6). This characteristic is absent in loblolly pine and loblolly-shortleaf pine hybrids. In addition, shortleaf pine may allocate more resources to coarse roots than stem mass compared with loblolly pine (Bradley and Will 2017), which may enhance its drought tolerance. High drought and fire tolerance contribute to its likely persistence in a drier and warmer future climate (Peters et al. 2020). Warmer temperatures in the winter months, as has been observed in the Ozarks (Stambaugh and Guyette 2004), may confer a competitive advantage to shortleaf pine because photosynthesis can take place while competing hardwoods are dormant (Guyette et al. 2007). Shortleaf pine regenerates from seed if conditions, such as bare mineral soil created through fire or scarification, prevail during seed crops (Yocom and Lawson 1977).

## Genetics

Shortleaf pine is a monoecious diploid species with wind-dispersed pollen and cones requiring 2 years to mature (figure 7) (table 1). Trees do not produce seed until 5 to 20 years of age, which can hinder

**Figure 7.** Shortleaf pine cones open to release seed with or without fire. (Photo by C. Pike, 2019)

**Table 1.** Summary of silvics, biology, and transfer considerations for shortleaf pine.

| Shortleaf pine, *Pinus echinata* Mill. | |
|---|---|
| Genetics | • Genetic diversity: high<br>• Gene flow: high |
| Cone and seed traits | • 2 to 73 cleaned seeds per pound (71 to 161 per kg) (Krugman and Jenkinson 2008) |
| Insect and disease | • Southern pine beetle<br>• Pales and eastern tip weevil<br>• Various cone and seed insects |
| Palatability to browse | • Few browse issues in its current range<br>• Northward movement to areas with different herbivores may alter its susceptibility |
| Maximum transfer distances | • In northern locations, local sources are best, but consider conservative application of the general rule (using seed from up to 5 o F (2.8 °C) warmer average annual minimum temperature<br>• In central locations sources should be moved northward no more than 7° F (3.9 °C) average annual minimum temperature<br>• In southern locations, it is best to use local seed zones latitudinally and conservatively diversify longitudinally |
| Species range-expansion potential | • Shortleaf pine is a good candidate for northward expansion due to drought tolerance, but insects may become problematic |

natural regeneration (Krugman and Jenkinson 2008). Seed is typically released from cone bracts in October and November. Hybridization with loblolly pine, with which it is sympatric across much of its range, is a concern because of potential losses to the genetic integrity of naturally regenerating forests or seed orchards (Stewart et al. 2010, 2013; Tauer et al. 2012). Regular burn intervals of 3 years or less can effectively select against hybrids and loblolly pine in mixed species stands (Stewart et al. 2015). Additional genetics research to improve marker-based identification of hybrids is needed to identify and remove advanced-generation hybrids from established seed orchards and restoration seed reserves (Stewart et al. 2016). The proportion of hybrids recruiting into regenerating stands is likely to increase with continued fire suppression (Stewart et al. 2015, Tauer et al. 2012). Climate change may also increase hybridization if phenology of flower production in loblolly and shortleaf pines become more synchronized (Tauer et al. 2012).

In the Missouri Ozarks, genetic variation is high with little divergence among populations sampled and no evidence of a prior genetic bottleneck (Hendrickson et al. 2018). Stewart et al. (2016) summarized prior work on isozymes and DNA markers that all describe the species as highly outcrossing with little genetic structure, increased differentiation between sources west and east of the Mississippi River, and high genetic diversity throughout the range. Hybrids with loblolly pine were more common in the western part of the range than east of the Mississippi River (Edwards and Hamrick 1995, Stewart et al. 2010), although genetic diversity between east and west were similar. Genetic improvement in shortleaf pine is promising (Gwaze et al. 2005a, 2005b), and seed orchards with improved seed are in use (Hossain et al. 2021).

## Seed-Transfer Considerations

In southern Illinois, shortleaf pine sources from Ohio, Mississippi, Missouri, Arkansas, Oklahoma, and Kentucky were similar in height, diameter, and survival after 27 years (Gilmore and Funk 1976). In New Jersey, local sources had the highest survival followed by those from northeast Tennessee and Missouri, which were 8 to 10 ft (2.4 to 3.6 m) shorter than the New Jersey source (Little 1969, Wells and Wakeley 1970).

Local sources were also best in Pennsylvania, but Tennessee sources were similar, followed by sources from Oklahoma and Georgia (Little 1969). Little (1969) attributed losses in survival and basal area in New Jersey and Pennsylvania sites to winter injury.

In southern range locations (Mississippi, southeast Louisiana, and southwest Georgia) southernmost sources were considerably taller than more northern sources (Wells and Wakeley 1970). Progeny tests in Arkansas revealed that shortleaf pine sources from the Ouachita National Forest had better growth than northerly sources from the Ozark National Forest (Hossain et al. 2021, Studyvin and Gwaze 2012). The same studies showed that eastern and western sources within the Ouachita National Forests did not differ significantly. North-south trends are complicated by the presence of loblolly pine hybrids in the south, which can alter the phenotype (Wells and Wakeley 1970). Local sources are best suited for areas along the northern range edge (Wells and Wakeley 1970). Seed sources originating from 5 to 7 °F (2.8 to 3.9 °C) warmer average annual minimum temperature have the fastest growth without sacrificing cold tolerance (Schmidtling 1994, 2001).

## Insects and Diseases

Shortleaf pine is highly susceptible to southern pine beetle (*Dendroctonus frontalis* Zimmerman) and its fungal associate, *Ceratocystis minor* (Hedgecock) Hunt (Cook and Hain 1987). Southern pine beetle continues to expand its range northward and is likely to remain an impediment to southern pines into the future (Lesk et al. 2017). Cone and seed insects are often major pests in shortleaf pine seed orchards, including Nantucket pine tip moth (*Rhyacionia frustrana* [Comstock]), which infests conelets (Yates and Ebel 1972). The insect species *Dioryctria amatella* Hulst and *Eucosma cocana* Kearfott cause seed loss on second-year cones (Ebel and Yates 1974). Other insects associated with seed losses included seedbugs such as *Leptoglossus corculus* Say and *Tetyra bipunctata* Herrich-Schaeffer and the seed worm *Laspeyresia* spp. Sawflies (*Neodiprion* spp.) can also damage female strobili (Bramlett and Hutchinson 1965). Pales (*Hylobius pales* Herbst) and eastern pine weevil (*Pissodes nemorensis* [Germar 1824]) are known to feed on bark tissue of young, vigorous seedlings (Land and Rieske 2006).

Shortleaf pine is relatively resistant to fusiform rust, (*Cronartium quercuum* [f. sp. fusiforme]) (Powers et al. 1981), the most economically important pathogen of southern pines. Root rot pathogens associated with shortleaf pine include littleleaf disease (*Phytophthora cinnamomi* [Mistretta 1984]) and annosus root disease (*Heterobasidion annosum* (Fr.) Bref. [1888]) [formerly known as *Fomes annosus*]) (Berry 1968). Annosus root disease can spread onto freshly cut stumps, usually after thinning, infecting the stand for 50 years or more. Shortleaf pine can also be a host to Comandra blister rust (*Cronartium comandrae* Pk.), although this pathogen is more common in the Western United States (Johnson 1997).

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# Longleaf Pine: Guidance for Seed Transfer Within the Eastern United States

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## Abstract

Longleaf pine (*Pinus palustris* Mill.) is a shade-intolerant conifer tree that occurs across the Southern United States from southeast Texas in the west to southeast Virginia in the east. The species and its associated ecosystem have declined sharply over the last several decades due to absence of fire and replacement with southern pines that have faster growth and higher reproductive potential. Genetic diversity of longleaf pine is high and population structure is low, with very little geographic-based differentiation. Seeds can be moved from a warmer to a colder hardiness zone (up to 5 °F [2.8 °C] lower average annual minimum temperature) to increase growth relative to local sources. Brown-spot needle blight is the most damaging disease of longleaf pine, contributing to seedling mortality in some cases. Damage from fusiform rust and southern pine beetle are generally minor compared with damage to loblolly pine (*P. taeda* L.), a common associated species. In the future, longleaf pine is likely to increase within its current range because of its tolerance to fire, drought, and wind and the increasing restoration planting efforts, but shade intolerance will hamper its success on stands with moderate to heavy hardwood competition.

## Introduction

Longleaf pine (*Pinus palustris* Mill.) is a long-lived, shade-intolerant, drought-tolerant, fire-dependent conifer species that is native across the southern portion of the Southeastern United States. Longleaf pine grows on sites ranging from poorly drained lowlands to low mountain ridges up to 2,000 ft (600 m) (Maceina et al. 2000). The species is known for its long needles (figure 1), relatively large cones and seeds, and "grass stage" juvenile growth habit. Longleaf pine ecosystems may have once occurred on 60 million acres (24 million hectares) across the Southern United States (Boyer 1990). Today approximately 3.5 million acres (1.4 million ha) of longleaf pine ecosystems remain (Kelly and Bechtold 1989), with the majority in a less than desirable state. This reduction is due to fire suppression and land conversion to nonforests or more commercially favorable pine species, such as loblolly pine (*P. taeda* L.).

**Figure 1.** Longleaf pine has exceptionally long needles. This planted seedling has recently emerged from the grass stage. (Photo by K. Dumroese, USDA Forest Service, 2009)

Longleaf pine ecosystems were considered among the most endangered in the United States (Noss et al. 1995), but recent surveys report increases in the larger (≤10 in [25 cm]) diameter size classes, reversing the previously observed decreasing trend (Oswalt and Guldin 2021).

Longleaf pine is most typically associated with sandy, acidic, infertile soils at low elevation, below 660 ft (200 m), often growing alongside other southern pines (i.e., shortleaf pine [*Pinus echinata* Mill], slash pine [*P. elliottii* Engelm.], and loblolly pine). A complex, diverse, herbaceous community is associated with, and sometimes endemic to, longleaf pine ecosystems in both montane (Maceina et al. 2000, Varner et al. 2003) and low-elevation forests (Brockaway et al. 2005). Frequent fires associated with longleaf pine ecosystems sustain understory plant communities and reduce competition from xeric hardwoods (Ford et al. 2010, Maceina et al. 2000). The complexity of understory communities is determined largely by the severity and frequency of fire (Boyer 1990, Stokes et al. 2010) with wiregrass (*Aristida strictais* Michx.) as a common associate of these ecosystems (Noss 1988). Seed germination is best on bare mineral soil, which favors the likelihood that the seedling's root collar is positioned at or below the soil level to protect from future fire (Jin et al. 2019) and drought (Wilson et al. 2022).

Longleaf pine timber is relatively heavy and strong compared with other pines, with a straight grain that is desirable by the forest products industry (Alden 1997). The species is significantly more windfirm than other southern pines (Johnsen et al. 2010), and its timber is especially important for utility poles (The Longleaf Alliance 2011). Pine straw derived from longleaf pine needles is commercially valued for landscaping (The Longleaf Alliance 2011).

Extensive conservation efforts by States and partners, notably The Longleaf Alliance (https://longleafalliance.org) and America's Longleaf (https://americaslongleaf.org), have continued to advance regeneration and restoration of longleaf pine ecosystems (Brockaway et al. 2006, Guldin et al. 2015). Containerized seedlings are preferred for restoration plantings because of substantial improvements in survival over bareroot stock types (Cram et al. 2010) (figure 2). Studies on container size and nitrogen regime during nursery culture have generated specifications for quality stock (Davis et al. 2011, Jackson et al. 2012).

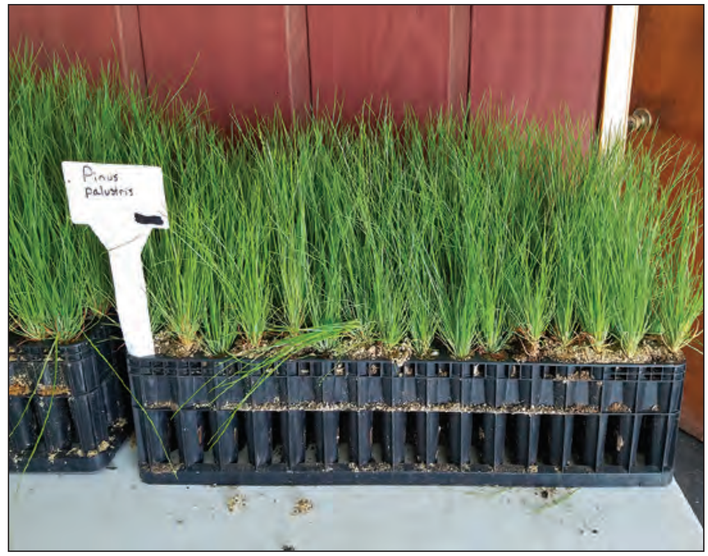

**Figure 2.** Longleaf pine containerized stock is generally more successful in planting than bareroot stock. (Photo by C. Pike, 2018)

While in the "grass stage," longleaf pine seedlings do not grow in height, a feature that is not shared with the other southern pines (figure 3). During this development phase, which can last from 2 to 10 years or more (Boyer 1990), carbon is primarily allocated to the root system, including a characteristically large tap root. Seedlings typically emerge from the grass stage when the root collar diameter reaches 1 in (2.5 cm) (Haywood et al. 2011, Knapp et al. 2018, Wahlenberg 1946). Grass stage seedlings with good root collar diameter and position (relative to the ground line) can survive most prescribed fires depending on a variety of site conditions and fire parameters (Jin et al. 2019, Knapp et al. 2018, Pile et al. 2017). The delayed height growth relative to other southern pines (Hooker et al. 2021) can complicate their use in plantation forestry, although the volume differences may decline or disappear in mature stands (Cram et al. 2010). Efforts to shorten this stage through silviculture and genetics have been studied (Nelson et al. 2003) but reduced belowground carbon allocation may be an undesirable tradeoff (Aubrey 2022).

Longleaf pine had at least one glacial refugia in southern Texas and northern Mexico (Schmidtling and Hipkins 1998), with a second refugia likely in Florida, the Caribbean, or both (Schmidtling 1999). Longleaf pine is forecast to do moderately well as the climate warms because of its tolerance to fire and drought (Wilson et al. 2022), but its shade intolerance will deter its establishment and survival in areas with encroaching hardwoods (Peters et al. 2020).

**Figure 3.** Longleaf pine seedlings remain in the grass stage for 2 to 5 or more years depending on site conditions. (Photo by C. Pike, 2018)

## Genetics

Longleaf pine is a monoecious and diploid species with high genetic variation, in part due to its wind pollination and ample seed dispersal (Grace et al. 2004). Opportunities for tree improvement are high for longleaf pine due to its prolific genetic variation and high-quality timber that are valued and supported by the timber industry (Samuelson et al. 2018, Schmidtling and White 1990). Seed orchards are commonly used for supplying seed for seedling production in nurseries (figure 4). Assessments of carbon isotopes δ13C, as a proxy for water use efficiency, among provenances and full-sib families demonstrates the potential to further improve drought tolerance through selection and breeding (Castillo et al. 2018, Samuelson et al. 2018). Similar to other pine species, most genetic variation occurs within populations relative to among populations as determined with allozyme (Hamrick et al. 1993) and microsatellite markers (Crane et al. 2019, Echt and Josserand 2018). Low allozyme-based FST values of 0.041 indicate that populations are not strongly differentiated (Schmidtling and Hipkins 1998).

Longleaf pine has relatively large seeds compared with other southern pines that are wind-dispersed (figure 5). The species naturally hybridizes with loblolly pine but is not likely to naturally hybridize with slash pine due to large phenological differences. Longleaf pine is not known to hybridize with shortleaf pine. The hybrid with loblolly pine is known as Sonderegger pine (*P. x sondereggeri* H. H. Chapm.) and has relatively fast early height growth compared with longleaf pine, but survival may be lower compared with loblolly pine (Schoenike et al. 1975). Seedlings that grow in height in nurseries (i.e., lacking a grass stage) are likely to be Sonderegger pines and are typically culled prior to outplanting (Schmidtling 1999).

## Seed-Transfer Considerations

Seed-transfer recommendations are based largely on plant hardiness zones, or the minimum temperatures for a locale as discussed in Schmidtling (2001) and Schmidtling and Sluder (1995). In general, seedlings can be planted at locations with 5 °F (2.8 °C) lower average annual minimum temperature. This transfer distance is consistent with Wells and Wakeley (1970), who found that seeds from 150 mi (241 km) south are generally favored for planting because their growth

**Figure 4.** Seed orchards are used for collecting much of the seed used for longleaf pine tree planting. (Photo by C. Pike, 2016)

exceeds local sources, except in northern locales where local sources may grow better. Longitudinal differences among populations (east to west) are minimal (Schmidtling 1999, 2001; Schmidtling and Hipkins 1998).

The understory plants of longleaf pine ecosystems are critical components for successful restoration of the ecosystem, including little bluestem (*Schizachyrium scoparium* [Michx.] Nash) and hairy lespedeza (*Lespedeza hirta* [L.] Hornem.) (Gustafson et al. 2018). A common garden study of six understory plant species showed that longitudinal transfer distances of 93 to 310 mi (150 to 500 km) and latitudinal transfer distances of 150 to 248 mi (150 to 400 km) were optimal (Giencke et al. 2018).


**Figure 5.** Longleaf pine seeds are relatively large compared with other southern pines. (Photo by V. Vankus, USDA Forest Service, 2023)

## Insects and Diseases

Longleaf pine is generally less susceptible to major pests and pathogens than other southern pines, but forest pests may be less well understood in longleaf pine ecosystems and could become problematic as restoration efforts increase (Barnard and Mayfield 2009). Relative to the other southern pines, longleaf pine is less susceptible to the southern pine beetle (*Dendroctonus frontalis* [Zimmerman]), apparently due to its strong response to insect feeding with high resin production (Hodges et al. 1979). More recent work has suggested two alternative hypotheses relative to loblolly pine: (1) longleaf pine may have coevolved more closely with the southern pine beetle, or (2) the spatial scale of longleaf pine occurrence may play a role in reducing the impact of southern pine beetles (Martinson et al. 2007).

Brown-spot needle blight, caused by the ascomycete *Lecanosticta acicola* (Thümen) A. Sydow., is the most important disease of longleaf pine, especially impacting seedlings in the grass stage (van der Nest et al. 2019). Genetic trials have shown that resistance to brown-spot disease is heritable and could be improved by selection and breeding (Gwaze et al. 2002, Lott et al. 2011, Nelson et al. 2005). Although fusiform rust does infect longleaf pine, the species is not considered to be susceptible as infection and tree damage levels are typically quite low relative to susceptible species such as loblolly and slash pines.

**Table 1.** Summary of silvics, biology, and transfer considerations for longleaf pine.

| Longleaf pine, *Pinus palustris* Mill. | |
|---|---|
| Genetics | • Genetic diversity: high<br>• Gene flow: high |
| Cone and seed traits | • 4,900 seeds per pound (10,800 per kg) (Krugman and Jenkinson 2008)<br>• Trees do not typically bear seeds until >20 years old<br>• Good cone crops occur every 5 to 7 years (Krugman and Jenkinson 2008) |
| Insect and disease | • Southern pine beetle<br>• Brown-spot needle blight |
| Palatability to browse | • Browse is rarely reported in longleaf pine |
| Maximum transfer distances | • Movement to cooler plant hardiness zone (5 °F [2.8 °C] lower average annual minimum temperature) is typically practiced; with added risk, movement up to 10 °F (5.6 °C) may be tolerated<br>• No east-west transfer limits are designated |
| Species range-expansion potential | • Longleaf pine is expected to be generally favored in a warming climate because of its adaptability to fire |

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# The Effect of Interim Cold Storage on Root Growth Potential of Hot-Lifted Western Redcedar and Coastal Douglas-Fir Seedlings

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## Abstract

Seedlings planted in the summer and early fall are still physiologically active and thus require special handling requirements to maintain quality. The effect of cold storage duration on potential seedling establishment for hot-lifted seedlings in western Canada and the Pacific Northwest is unclear. This study tested the effect of interim storage duration on hot-lifted, fall planted western redcedar (*Thuja plicata* Donn ex D. Don) and coastal Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) seedling quality. Root growth potential (RGP) and cold hardiness (via chlorophyll fluorescence) were used to evaluate seedling quality. Results showed that coastal Douglas-fir and western redcedar seedling quality were not compromised during 2 weeks of interim cold storage in closed boxes at 4 °C (39 °F). After 3 or 4 weeks of storage, RGP declined for both species, although the coastal Douglas-fir would still have been acceptable to plant according to current British Columbia Ministry of Forests criteria. This paper was presented at the Joint Annual Meeting of the Western Forest and Conservation Nursery Association and the Forest Nursery Association of British Columbia (Portland, OR, September 19–21, 2023).

## Introduction

Approximately 80 percent of container forest seedlings in western Canada and the Pacific Northwest are harvested and packaged when dormant in the late fall and early winter and stored frozen for up to 6 months until planting the following spring. The other 20 percent of container seedlings are harvested in the summer or fall and outplanted shortly thereafter. As foresters look for strategies to cope with changing climates and labor shortages, alternative planting dates may become more common. Compared with seedlings destined for frozen storage, seedlings harvested for immediate planting are still physiologically active and are thus referred to as “hot lifted” and “hot planted.” To maintain the quality of hot-lifted seedlings, specific requirements regarding temperature during handling must be met because the seedlings generate heat via maintenance respiration. In response to these requirements, restrictive stock handling stipulations have been put in place to ensure seedling quality is not compromised. However, the underlying scientific basis for some of these guidelines is unclear.

The general handling guidelines to care for seedlings during hot planting is to keep the seedlings cool and plant them as soon as possible (Dunsworth 1997, Kiiskila 1999, Landis et al. 2010, Paterson et al. 2001, Stjernberg 1997). A 10 °C (18 °F) increase in temperature approximately doubles seedling respiration rate (Kramer and Kozlowski 1979). Thus, the temperature inside a closed box of seedlings can quickly increase (Binder and Fielder 1995), resulting in a loss of stored carbohydrates and vigor (Landis et al. 2010). Therefore, the recommendation is to keep hot-lifted seedlings refrigerated at 2 to 10 °C (35 to 50 °F) once packaged, with 2 °C (36 °F) being the ideal interim storage temperature (Grossnickle et al. 2020). Since most commercial refrigeration units on trailers and cold storage units can fluctuate up and down by 2 °C (4 °F), the lowest temperature setting used to prevent inadvertent freezing of hot-lifted stock is usually 4 °C (39 °F).

Seedlings picked up from the nursery in the early morning or evening and planted shortly thereafter are often transported without refrigeration and stored onsite in a field cache under shade. To compensate for the lack of refrigeration, hot-lifted seedlings are typically packaged upright without bags in waxed seedling boxes so that the boxes can be opened to allow for heat dissipation and irrigation (Kiiskila 1999, Landis et al. 2010). At remote planting sites, it may be a week from the time seedlings are packaged at the nursery until they are planted. Under these conditions, the use of refrigerated storage at the nursery, during transportation, and in the field cache is important to maintain seedling quality. Because temperature interacts with the length of time from nursery harvest to planting, some reforestation contracts have time stipulations specifying that the seedling boxes be opened within 5 days of being closed at the nursery (Anonymous 2021).

Root growth after planting is critical for seedling survival and establishment (Grossnickle 2005, Grossnickle and Ivetić 2022). Thus, the seedling's ability to grow roots under optimum conditions is commonly assessed (i.e., root growth potential [RGP]) prior to planting (Haase 2008, Nelson 2019). RGP tests are usually not performed, however, on hot-lifted seedlings as is done for dormant frozen- or cold-stored seedlings prior to planting (Moeller 2022). Nonetheless, root growth after planting is still considered very important to the successful establishment of hot-planted seedlings (Grossnickle and MacDonald 2021). Sufficient cold hardiness of the shoots to withstand potential low temperatures is another trait required for successful hot planting in the fall (Grossnickle and MacDonald 2021). In British Columbia (BC), cold hardiness is routinely measured each fall via chlorophyll fluorescence to determine when seedlings are ready to be harvested for frozen storage (Moeller 2018). Measurement of the optimal quantum yield (i.e., maximum fluorescence/variable fluorescence from photosystem II) provides a direct estimate of the overall photosynthetic efficiency (Mohammed et al. 1995) and thus can be used to detect cold damage to the photosynthetic system (Ritchie 2005, Rose and Haase 2002).

While there are various recommendations and contract stipulations as to interim storage temperature and duration for hot-lifted seedlings in western Canada and the Pacific Northwest, the effect of storage duration under ideal temperatures on potential seedling establishment success is not known. In Finland, even a few days in dark, closed boxes reduced root growth and cold hardiness after planting for hot-lifted, fall-planted seedlings, although the boxes were not stored under refrigerated conditions (Luoranen et al. 2019). Most stipulations regarding how soon seedlings must be planted after nursery harvest do not specify an interim storage temperature. The ability to safely increase interim storage duration would increase logistical flexibility during the hectic hot-lift/hot-plant season. Thus, the objective of this trial was to examine the effect of interim storage duration on hot-lifted, fall planted western redcedar (*Thuja plicata* Donn ex D. Don) and coastal Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco var. *menziesii*) seedling quality.

## Methods

### Seedlings

Coastal Douglas-fir and western redcedar seedlings from a large order of hot-lifted seedlings grown commercially at Arbutus Grove Nursery in North Saanich, BC were used for this study. After grading, the coastal Douglas-fir and western redcedar average shoot height for the entire crop was 22.9 ± 2.8 cm (9.0 ± 1.1 in) and 26.3 ± 4.0 cm (10.3 ± 1.6 in), respectively, and the average stem diameter was 3.4 ± 0.4 mm (0.13 ± 0.01 in) and 2.8 ± 0.4 mm (0.11 ± 0.01 in), respectively. Coastal Douglas-fir seedlings were grown in 412A/10S Styroblocks™ (42-mm [1.62-in] diameter with 116-mm [4.58-in] depth; Beaver Plastics, Alberta, Canada), and the western redcedar were grown in 412B Styroblocks™ (36-mm [1.42-in] diameter with 116-mm [4.58-in] depth). The seedlings were grown under standard commercial growing regimes like those described in Wenny and Dumroese (1990, 1992) and Landis et al. (1989). For the coastal Douglas-fir, this regime entailed sowing the seeds into a double-poly greenhouse at the end of March and growing them under cover until mid-June at which time the poly was removed and the seedlings were exposed to full sunlight. In early July, the coastal Douglas-fir received 4 weeks of 14-hr blackout (i.e., short-day) treatment to induce budset, which was carried out with increasing levels of drought stress prior to each irrigation. The western redcedar seedlings were sown in early February in a double-poly greenhouse and grown until mid-April when they were moved outside and grown under a low fertilizer regime to reduce shoot growth.

Ten 10-seedling bundles of each species were randomly selected during hot-lift operations on September 12, 2022. Eight bundles of each species were placed upright in a poly bag inside one waxed seedling box. Both the bag and box were closed. The box was then stored on a wooden pallet in an operational cold storage unit at Arbutus Grove Nursery at 4 °C (39 °F) ± 2 °C (4 °F) (figure 1). Two bundles of each species were packaged into a cardboard box with a frozen ice pack and shipped to the University of Northern British Columbia (UNBC) I.K. Barber Enhanced Forestry Laboratory in Prince George, BC. Two bundles of each species were sent each week for 5 consecutive weeks. Seedlings in the first shipment (week 0) did not have any time in cold storage before being transported to UNBC. Each subsequent shipment underwent an additional week in cold storage. The fifth shipment (week 4) spent an extra day in cold storage as the regular shipment date was a national holiday. It took 1 to 2 days from the time seedlings left the nursery until temporary placement in a walk-in cooler at 4 °C (39 °F) at UNBC.

## Root Growth Capacity

Within a half day of arrival, seedlings sent to UNBC were taken from the cooler into a lab at room temperature (20 °C [68 °F]) where root collar diameter (RCD) and height were measured. Seedlings were labelled and potted individually by hand into 3.8-L (1-gal) pots filled with moistened ProMoss (Premier Tech Horticulture, Rivière-du-Loup, Québec) 100 percent *Sphagnum* peat moss. Each week, the 40 seedlings were placed into a Conviron PGR15 (Conviron Canada, Winnipeg, Manitoba) growth chamber (unit A) in a 10 by 4 rectangle of alternating coastal Douglas-fir and western redcedar (figure 2). The pots were then watered to field capacity. The growth chamber was set to 14-hr days at 460 µmol/s2/m2 and 10-hr nights. The temperature was set to 22 °C (72 °F) during the day and 16 °C (61 °F) at night, and the relative humidity was 50 percent both day and night. These settings were chosen to mimic typical conditions seedlings may experience when planted on Vancouver Island in the early fall. After 7 days, all seedlings in growth chamber unit A were moved to a similar Conviron PGR15 growth chamber (unit B) set to the same light, temperature, and


**Figure 1.** Trial seedlings were stored in a waxed seedling box on a wooden pallet in a commercial cold storage cooler. (Photo by Steven B. Kiiskila, 2022)

**Figure 2.** Western redcedar and coastal Douglas-fir seedlings were placed in growth chambers to determine root growth potential following varying cold-storage durations. (Photo by Jennifer Baker, 2022)

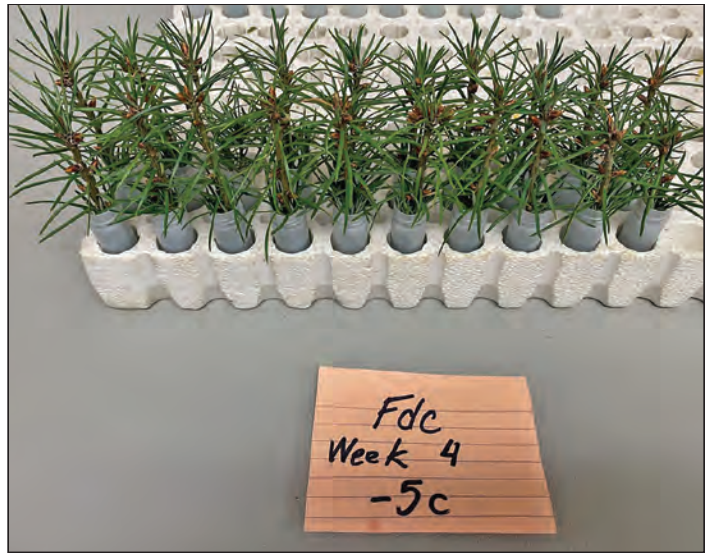



**Figure 3.** Seedling shoot tips were placed in vials prior to freeze treatment and chlorophyll fluorescence measurement. This photo shows Coastal Douglas-fir before the -5 °C (23 °F) treatment following 4 weeks of storage and 2 weeks in the growth chambers. (Photo by Jennifer Baker, 2022)

relative humidity settings and once again watered to field capacity. Seedlings were moved to the second growth chamber after 1 week to account for potential differences in growth chamber conditions.

After 2 weeks in the growth chambers, seedlings were unpotted and the peat moss was gently removed from the roots. RGP of each seedling was then classified using the following modified Burdett (1979) scale:

0 – no roots

1 – some new roots < 10 mm (0.30 in)

2 – 1 to 9 new roots ≥ 10 mm (0.39 in)

3 – 10 to 19 new roots ≥ 10 mm (0.39 in)

4 – 20 or more new roots > 10 mm (0.39 in)

The seedling shoots were also assessed as either dead, inactive, swollen, or flushed and any signs of foliar disease or necrosis were noted.

## Shoot Cold Hardiness

After the RGP assessment, shoot cold hardiness was assessed by following current British Columbia Government procedures (Moeller 2022). The top 10 cm (3.9 in) of each shoot was severed and placed in a vial filled with water (figure 3). The vials were then placed in a chest freezer at 4 °C (39 °F) in the dark, after which the temperature was ramped down to -5 °C (23 °F) over 1 hour, kept at -5 °C (23 °F) for 1 hour, and then ramped back up to 4 °C (39 °F) over 1 hour. The vials were then placed in a growth chamber at 6 °C (43 °F) to thaw in the dark. After 8 hours, the growth chamber lights were turned on and the temperature was increased to 24 °C (75 °F) for another 8 hours. Finally, the lights were turned off again and seedlings were kept in the dark for a minimum of 20 min to ensure they were in a fully dark-adapted state.

The dark-adapted maximum quantum yield of PSII ($F_v/F_m$) was then measured using a pulse modulated chlorophyll fluorometer Opti-Sciences OS1p (Opti-Sciences, Inc., Hudson NH). The $F_v/F_m$ reading represents an index of cold injury following freezing, with values greater than or less than 0.65 classified as either alive or dead, respectively. These steps were then repeated at -12 °C (10 °F) on the same samples for week 0 (no storage) seedlings. Because all seedlings failed the freezing test at -12 °C (10 °F) in week 0, it was decided to test cold hardiness at -5 °C (23 °F) and -8 °C (18 °F) for the remaining 4 weeks. Results from the colder exposure of -8 °C (18 °F) should be interpreted with caution, as the same sample was used to test both 5 °C (23 °F) and -8 °C (18 °F), rather than testing new samples as is typically done.

## Data Analysis

An analysis of covariance (ANCOVA) was used to analyze the statistical significance of RGP and quantum yield differences between weeks for each species using RStudio (version 2022.12.0+353, Posit, Boston, MA). Seedling height and RCD were set as covariates to account for possible interactions due to differences in height and RCD between weekly measurements. To determine if there was a relationship between seedling height and RCD, the measurements were plotted against one another for each species. No discernible relationship for either species occurred, thus height and RCD were plotted separately, which showed the data was variable enough to exclude an interaction between the two covariates.

Species were analyzed separately, and Tukey's Honest Significant Difference test was used to determine the significance of differences in weekly measured parameters. Differences with a p-value ≤ 0.05 were considered significant. Analyses were performed on RGP and dark-adapted maximum quantum yield after exposure to -5 °C (23 °F) and -8 °C (18 °F).

# Results

## Root Growth Potential

There was a statistically significant ($p = 0.05$) decline in the number of new roots greater than 1 cm (0.39 in) with increasing cold-storage duration for both species (figure 4). Variability in new root growth among seedlings also increased with increasing cold storage, especially in the western redcedar (figures 5 and 6), which had one dead seedling with no new root growth after 3 weeks of storage and two dead seedlings after 4 weeks of cold storage.

## Seedling Shoot Condition

After 2 weeks in the growth chamber, 5 and 10 percent of western redcedar seedlings that had received 1 or 2 weeks of cold storage, respectively, grew new foliage. Swollen buds were observed on 20 percent of coastal Douglas-fir seedlings that were not cold stored after 2 weeks in the growth chamber, compared with 10 percent of those that were cold stored for 1 week.

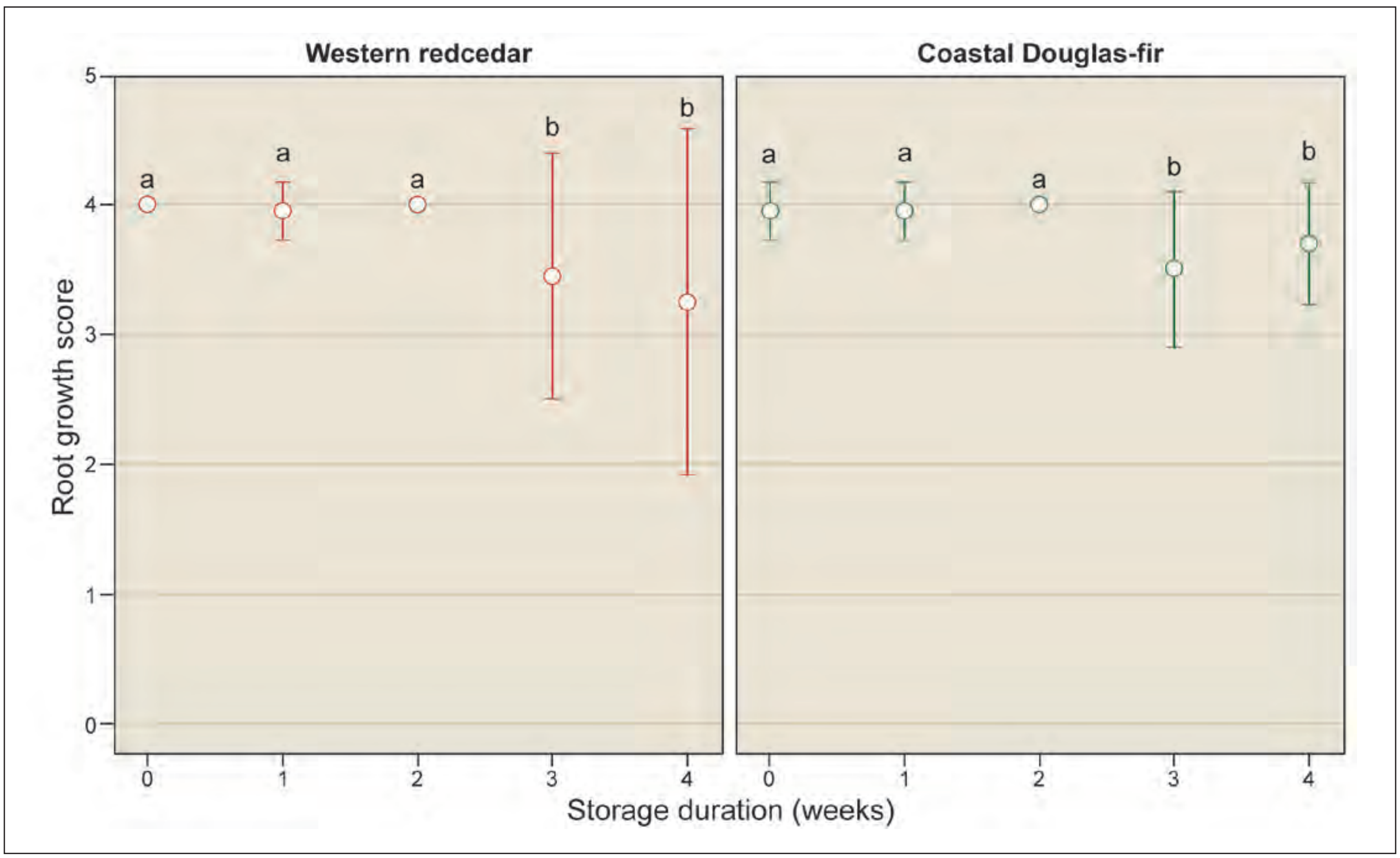



**Figure 4.** Mean RGP values varied for western redcedar and coastal Douglas-fir seedlings stored in a closed seedling box in cold storage at 4 °C (39 °F) for 0 to 4 weeks. Vertical bars are standard deviations of the mean. Weeks for each species with the same letter are not significantly different ($p = 0.05$)


**Figure 5.** Western redcedar seedlings previously stored in a closed seedling box in cold storage at 4 °C (39 °F) for 0 to 3 weeks, and then grown for 2 weeks in a growth chamber exhibited varying levels of root growth. The RGP of seedlings stored for 4 weeks did not differ significantly than those stored for 3 weeks and are thus not shown for brevity. (Photos by Jenifer Turner, 2022)

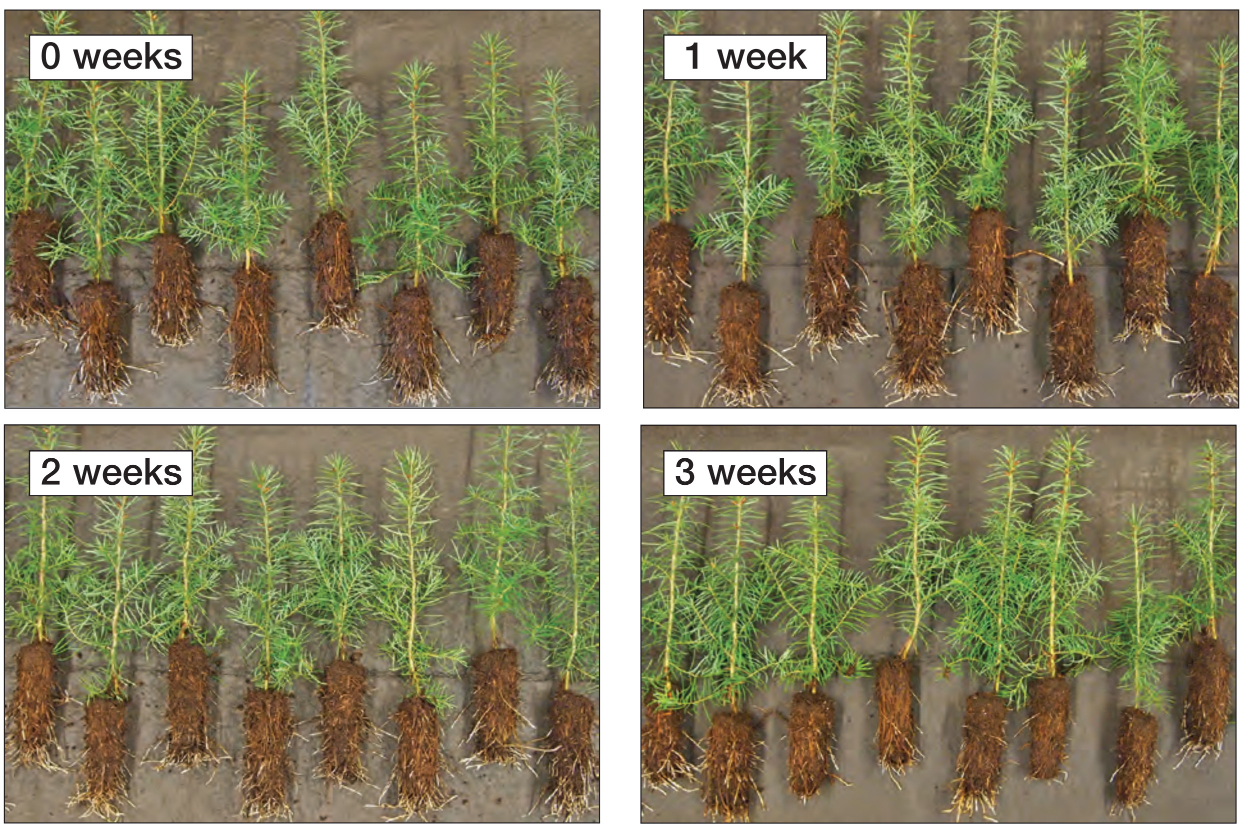



**Figure 6.** Coastal Douglas-fir seedlings previously stored in a closed seedling box in cold storage at 4 °C (39 °F) for 0 to 3 weeks, and then grown for 2 weeks in a growth chamber exhibited varying levels of root growth. The RGP of seedlings stored for 4 weeks did not differ significantly than those stored for 3 weeks and are thus not shown for brevity. (Photos by Jenifer Turner, 2022)

Coastal Douglas-fir seedlings in the longer storage treatments did not have bud swelling, although one of the terminal buds of a seedling stored for 2 weeks began to flush. Three western redcedar seedlings (one from the 3-week and two from the 4-week cold storage treatment) were assessed as dead during the RGP assessment. Foliar necrosis was also observed on four of the western redcedar seedlings cold stored for 3 weeks and on one stored for 4 weeks (figure 7). There was no seedling mortality or foliar damage observed in the coastal Douglas-fir.

### Shoot Cold Hardiness

Maximum quantum yield among seedlings after exposure to -5 °C (23 °F) and -8 °C (18 °F) varied considerably. After the -5 °C (23 °F) exposure, the maximum quantum yield valves for both species and all storage durations were deemed high at ≥65. Statistically significant differences occurred among storage durations for both species, but there was no clear cold hardiness trend (figure 8a). The maximum quantum yield after the -5 °C (23 °F) exposure was similar between species.

Overall, maximum quantum yield means for seedlings cold stored 1 to 4 weeks after exposure to -8 °C (18 °F) was lower and more variable than exposure at -5 °C (23 °F) for both the western redcedar and coastal Douglas-fir. Maximum quantum yield from all test dates for both species was ≤65, the value required to pass the BC Ministry of Forests cold

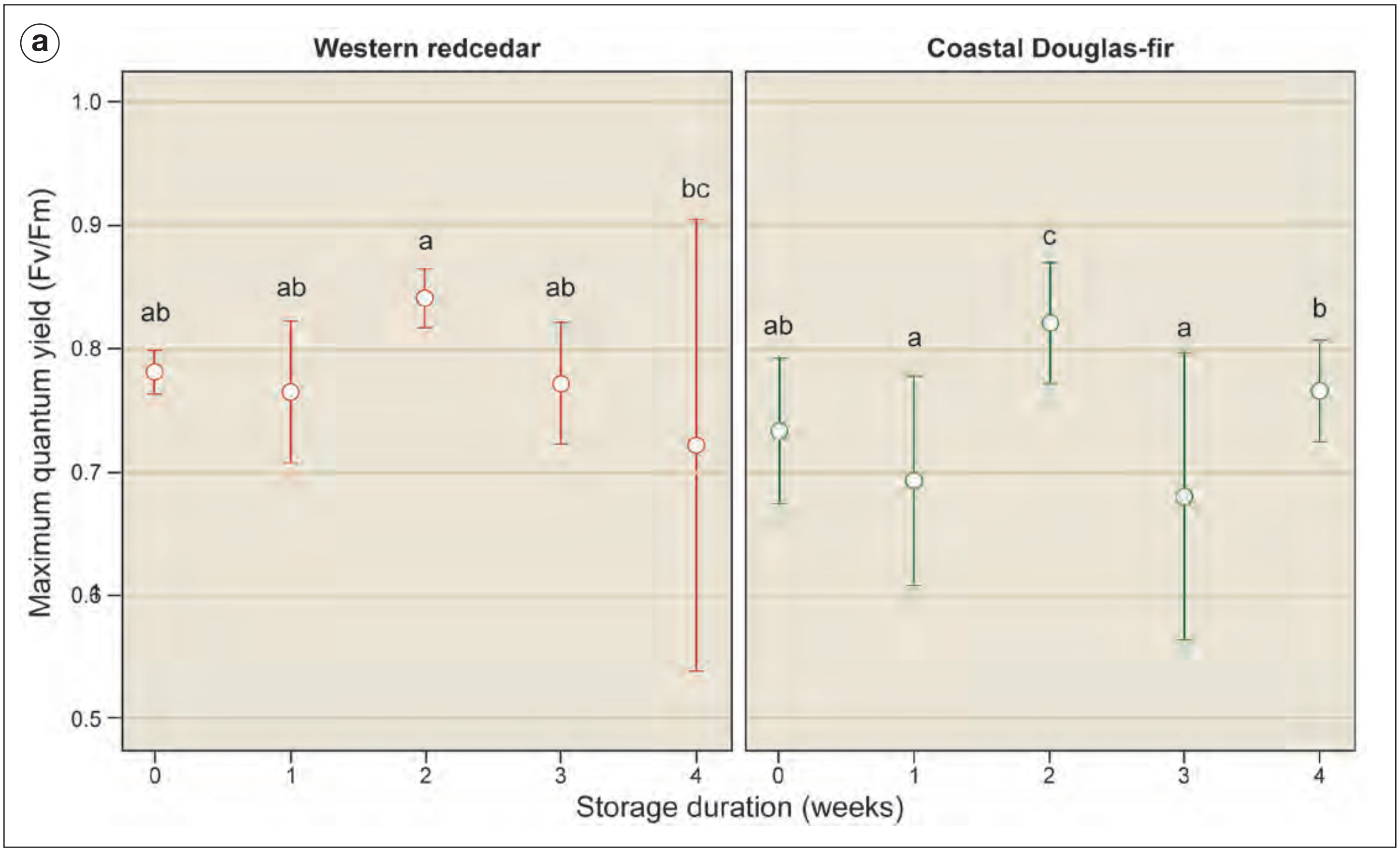

**Figure 7.** Foliar necrosis occurred on a western redcedar seedling after 3 weeks of cold storage and 2 weeks in a growth chamber. (Photo by Jennifer Baker 2022)

hardiness test for storability. Although statistically significant differences in quantum yield means were found among storage durations in both species, there was no clear cold hardiness trend (figure 8b). The maximum quantum yield after the -8 °C (18 °F) exposure was more variable and slightly lower in western redcedar compared with coastal Douglas-fir.

## Discussion

Results from this trial suggest that hot-lifted, fall-planted western redcedar and coastal Douglas-fir can be kept in closed boxes at 4 °C (39 °F) for at least twice the current BC Government stock handling guideline of 5 days (Anonymous 2021). Summer- and fall-planted southern pines (*Pinus* spp.) have been safely stored at 2 °C (35 °F) for 4 to 6 weeks (Grossnickle and South 2014, Jackson et al. 2012). Thus, longer storage durations have been successful. In contrast, no more than 1 week of storage in closed boxes is recommend for Norway spruce (*Picea abies* [L.] Karst.) and Scots pine (*Pinus sylvestris* L.) in Finland (Luoranen et al. 2019). Most stock handling recommendations do not specify an interim storage temperature at the nursery or field cache, or simply recommend that seedlings be kept below 10 °C (50 °F). Seedlings in this trial were stored under cool conditions, thereby slowing respiration and conserving carbohydrates. While there was a significant decline in RGP after 3 and 4 weeks of cold storage, the RGP results would still deem coastal Douglas-fir acceptable to plant according to current BC Ministry of Forests RGP evaluation criteria. Current RGP criteria used by the Ministry require a value of 3.0 on the Burdett RGP index (Burdett 1979) after 1 week in the greenhouse or growth chamber, which is only four new roots longer than 10 mm (0.39 in). A score of zero (no new roots) would negate the sample and require a retest, thus the western redcedar stored for 3 and 4 weeks in this trial would technically not be approved for planting without further investigation as there was some mortality.

The correlation between RGP and outplanting performance is weak at best (Simpson and Ritchie 1996). Nonetheless, RGP tests can provide valuable information regarding seedling quality. Knowing that the seedlings to be planted have the potential to grow a certain number of roots under ideal conditions assures the nursery and land managers that the seedlings are



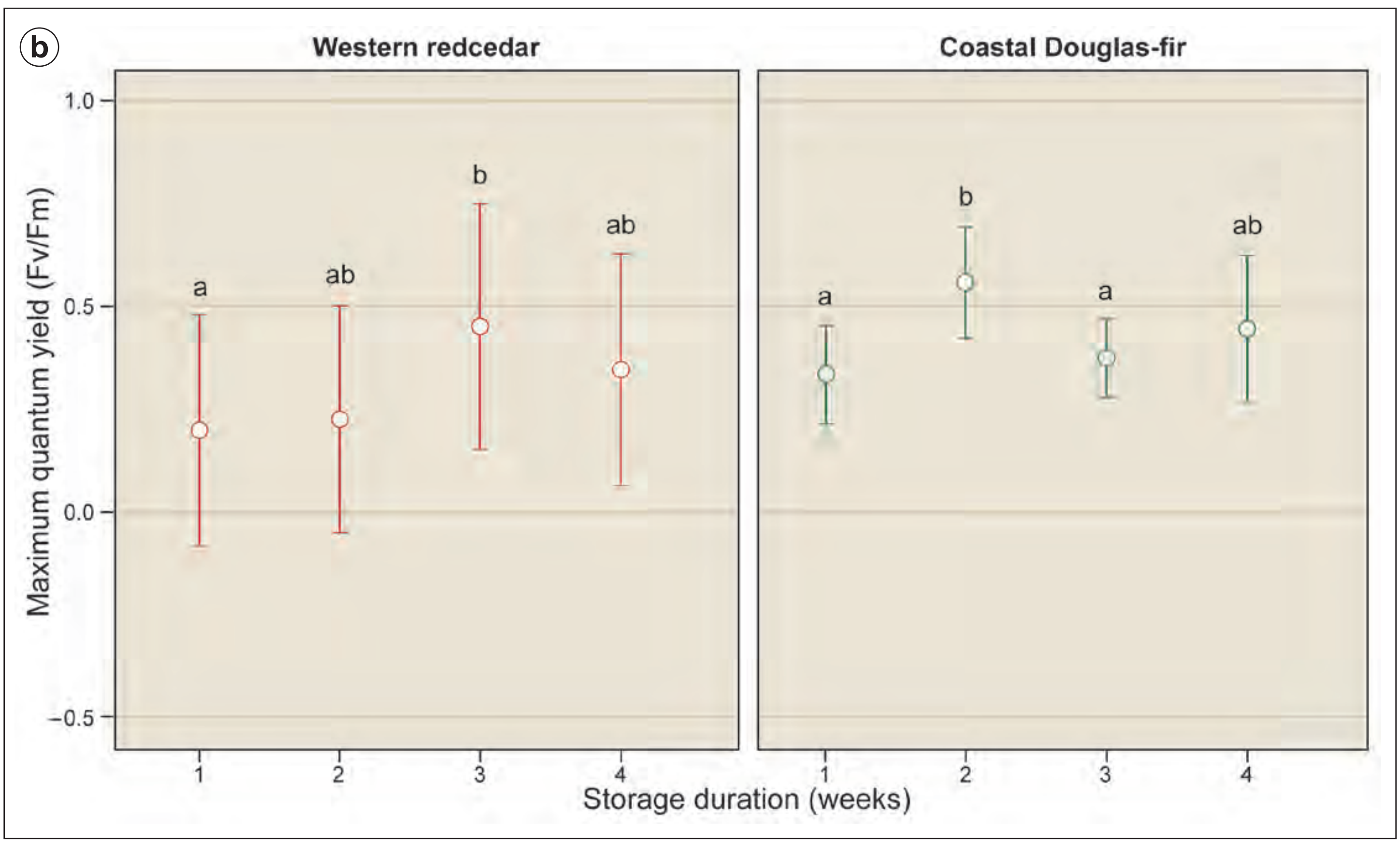




**Figure 8.** Mean dark-adapted maximum quantum yield values of western redcedar and coastal Douglas-fir seedlings varied by storage duration after exposure to (a) -5 °C (23 °F) or (b) -8 °C (18 °F). Vertical bars are standard deviations of the mean. Weeks for each species with the same letter are not significantly different (p = 0.05).

not compromised. The interpretation of RGP test results is affected by variations in test environment, test duration, species, season, and rating criteria. Various iterations of the Burdett (1979) RGP index are in use, such as the four-point scale used for commercial RGP screening at the I.K. Barber Enhanced Forestry Lab at UNBC, to which an additional classification was added to this trial for increased precision. Some RGP testing laboratories count all the new roots larger than a certain size (e.g., 10 mm [0.39 in]), although a threshold RGP value may exist after which more new roots do not result in increased aboveground growth (Nelson 2019).

RGP test results on hot-lifted seedlings should be interpreted with caution. Until a standardized RGP test procedure is developed, the test environment should be considered when interpreting RGP values. For example, because conifers primarily use current photosynthate for root growth (van den Driessche 1987, Villar-Salvador et al. 2015), root growth is expected to be greater under higher light intensity and duration. Healthy seedlings may not grow roots even under ideal environmental conditions due to seasonal periodicity in root growth, which may further be influenced by nursery cultural practices such as blackout or short-day treatment (Grossnickle and Ivetić 2022). Understanding all factors will help the nursery and forester to make changes to the nursery culture, planting date, or both to optimize seedling quality.

Hot-lifted seedling boxes are sometimes opened upon arrival at the planting site if they will not be planted in a day or two due to concerns that dark conditions reduce seedling quality (Lavender 1989). Some recommendations even suggest seedlings be removed from refrigerated storage into a warmer ambient environment so that the boxes can be opened (Anonymous 2021). In this trial, seedlings kept in the dark did not have adverse effects on RGP after 2 weeks. The closed seedling box, however, can be conducive for seedling disease (Camm et al. 1994). While seedlings were not cold hardy enough to tolerate -8 °C (18 °F), they were sufficiently hardy to -5 °C (23 °F). Thus, it is unlikely the western redcedar mortality and foliar damage was caused by the storage at 4 °C (23 °F). Seedling cold hardiness was also not impacted by the duration of cold storage. This agrees with previous studies on Douglas-fir (Ritchie 1982) and Sitka spruce (Cannell et al. 1990) where freezing tolerance was found to be maintained throughout cooler storage.

Hot-lifted seedlings planted in the summer or fall are typically stood upright in waxed seedling boxes without a bag so that stock can be cooled if the boxes are opened and so any irrigation water will drain. On the other hand, fall/winter lift stock to be freezer stored are packaged inside a poly or poly-paper bag in a waxed seedling box to prevent moisture loss and desiccation. In this trial, the seedlings were stood upright inside a closed poly bag to remove the potential variable of moisture loss. While properly hardened seedlings have developed a high level of drought tolerance by harvest, the potential moisture loss from hot-lifted seedlings packaged and stored for a couple of weeks in boxes without bags should be investigated because desiccation of root systems prior to outplanting can negatively impact seedling establishment (Genere and Garriou 1999). Preliminary, nonreplicated weight measurements of a hot-lifted box of Douglas-fir stored at 4 °C (23 °F) without a bag declined in total weight by 1, 3, 5 and 8 percent after 1, 2, 3, and 4 weeks, respectively.

## Conclusions

Interim storage is an operational handling step that is required in the process of moving hot-lifted seedlings from the nursery to the planting site. Increasing the interim storage duration of hot-lifted seedlings would allow for more flexibility in the reforestation pipeline. Results from this trial show that coastal Douglas-fir and western redcedar seedling quality were not compromised during 2 weeks of interim cold storage in closed boxes. Future studies could examine storage effects on different species during the summer hot-lift period. It is recommended that RGP test conditions be standardized and a more detailed root classification system be used to aid in evaluation of the results.

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# Forest Nursery Seedling Production in the United States—Fiscal Year 2022

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## Abstract

Forest nursery production for the 2022 planting season was more than 1.4 billion tree seedlings (including more than 18 million container seedlings imported from Canada). Approximately 70 percent of seedlings were produced as bareroot stock. Only a small portion (3 percent) of seedlings were hardwood species. Based on this total number of seedlings and estimated planting densities in each State, more than 2.7 million ac (1,127,348 ha) were planted. Approximately 82 percent of production and planting occurred in the Southern States, while 14 and 4 percent were planted in the Western and Eastern States, respectively. In 2022, number of tree seedlings planted increased in the Western and Southern States and decreased in the Eastern States compared with the previous year.

## Background

This annual report summarizes forest nursery seedling production in the United States. The number of seedlings reported is used to estimate the number of acres of forest planting per year. Prepared by the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) and State, Private, and Tribal Forestry, this report includes State-by-State breakdowns, regional totals, and an analysis of data trends. Universities in the southern, eastern, and western regions of the United States made an effort to collect data from all the major producers of forest and conservation seedlings in the 50 States. Forest and conservation nursery managers provided the information presented in this report. Because all data are provided voluntarily by outside sources and some data are estimated, caution must be used in drawing inferences.

## Methodology

State, Private, and Tribal Forestry, in collaboration with Auburn University, the University of Idaho, and Purdue University, produced the data for this report. These universities collected forest tree seedling production data directly from the forest and conservation nurseries that grow forest tree seedlings in their region of the United States (Auburn University collected from 12 States in the Southeast, the University of Idaho collected from 17 States in the West, and Purdue University collected from 21 States in the Northeast and Midwest). The estimate of planted acres for each State was calculated using FIA estimates of planting densities. In addition, FIA average annual estimates of tree planting area based on ground-plot data that States collected during 5-, 7-, or 10-year periods is included. FIA estimates of acres of trees planted by State may not correlate with nursery production surveys because nurseries do not report shipments across State lines. Total acres by region, however, provide a reasonable estimate of planted acreage. Data collected are reported for both hardwood and conifer species by bareroot and container seedlings produced (table 1) and by estimated acreage planted of each (table 2).

Table 1. Hardwood and conifer tree seedling production for each State and each region during the 2022 planting year.

| State | Hardwood bareroot seedlings produced | Hardwood container seedlings produced | Total hardwood seedlings produced | Conifer bareroot seedlings produced | Conifer container seedlings produced | Conifer container seedlings imported | Total conifer seedlings produced | Total seedlings produced |
|---|---|---|---|---|---|---|---|---|
| **Southeast** | | | | | | | | |
| Florida | 1,111,000 | 60,000 | 1,171,000 | 40,703,000 | 896,000 | — | 41,599,000 | 42,770,000 |
| Georgia | 5,399,000 | — | 5,399,000 | 191,740,000 | 146,129,000 | 90,460 | 337,959,460 | 343,358,460 |
| North Carolina | 373,000 | — | 373,000 | 55,725,000 | 13,628,000 | — | 69,353,000 | 69,726,000 |
| South Carolina | — | — | — | 220,218,000 | 3,000 | — | 220,221,000 | 220,221,000 |
| Virginia | 1,128,000 | — | 1,128,000 | 25,916,000 | 570,000 | — | 26,486,000 | 27,614,000 |
| **Regional Totals** | **8,011,000** | **60,000** | **8,071,000** | **534,302,000** | **161,226,000** | **90,460** | **695,618,460** | **703,689,460** |
| **South Central** | | | | | | | | |
| Alabama | 3,674,000 | 15,000 | 3,689,000 | 97,023,000 | 68,963,528 | — | 165,986,528 | 169,675,528 |
| Arkansas | 11,685,000 | — | 11,685,000 | 92,288,000 | — | — | 92,288,000 | 103,973,000 |
| Kentucky | 469,030 | — | 469,030 | 78,920 | — | — | 78,920 | 547,950 |
| Louisiana | — | — | — | — | 45,708,000 | — | 45,708,000 | 45,708,000 |
| Mississippi | — | 178,000 | 178,000 | 69,047,000 | 11,503,000 | — | 80,550,000 | 80,728,000 |
| Oklahoma | 606,000 | 4,000 | 610,000 | 3,570,000 | 85,000 | — | 3,655,000 | 4,265,000 |
| Tennessee | 2,164,000 | — | 2,164,000 | 2,075,000 | — | — | 2,075,000 | 4,239,000 |
| Texas | — | — | — | 68,769,000 | — | — | 68,769,000 | 68,769,000 |
| **Regional Totals** | **18,598,030** | **197,000** | **18,795,030** | **332,850,920** | **126,259,528** | **0** | **459,110,448** | **477,905,478** |
| **Northeast** | | | | | | | | |
| Connecticut | — | — | — | — | — | — | — | — |
| Delaware | — | — | — | — | — | — | — | — |
| Maine[1] | — | 5,500 | 5,500 | — | 3,516 | 4,300,000 | 4,303,516 | 8,609,016 |
| Maryland | 992,775 | 310,000 | 1,302,775 | 947,175 | 10,000 | — | 957,175 | 2,259,950 |
| Massachusetts | 300 | — | 300 | 3 | — | — | 3 | 303 |
| New Hampshire | 18,800 | — | 18,800 | 347,025 | — | — | 347,025 | 365,825 |
| New Jersey | 36,025 | 15,000 | 51,025 | 1,960 | 10,000 | — | 11,960 | 62,985 |
| New York | 249,100 | — | 249,100 | 329,100 | 24,500 | — | 353,600 | 602,700 |
| Pennsylvania | 300,445 | 1,125 | 301,570 | 1,278,988 | 300 | — | 1,279,288 | 1,580,858 |
| Rhode Island | — | — | — | — | — | — | — | — |
| Vermont | 2,000 | 400 | 2,400 | 120,200 | 100 | — | 120,300 | 122,700 |
| West Virginia | — | — | — | — | — | — | — | — |
| **Regional Totals** | **1,599,445** | **332,025** | **1,931,470** | **3,024,451** | **48,416** | **4,300,000** | **7,372,867** | **13,604,337** |
| **North Central** | | | | | | | | |
| Illinois | 807,550 | 5,175 | 812,725 | 98,000 | 965 | — | 98,965 | 911,690 |
| Indiana | 1,849,664 | 65 | 1,849,729 | 723,925 | — | — | 723,925 | 2,573,654 |
| Iowa | 644,625 | — | 644,625 | 165,825 | — | — | 165,825 | 810,450 |
| Michigan[1] | 3,187,834 | 10,000 | 3,197,834 | 9,609,174 | 12,977,410 | 65,800 | 22,652,384 | 25,850,218 |

Table 1 *(continued)*. Hardwood and conifer tree seedling production for each State and each region during the 2022 planting year.

| State | Hardwood bareroot seedlings produced | Hardwood container seedlings produced | Total hardwood seedlings produced | Conifer bareroot seedlings produced | Conifer container seedlings produced | Conifer container seedlings imported | Total conifer seedlings produced | Total seedlings produced |
|---|---|---|---|---|---|---|---|---|
| Minnesota[1] | 589,854 | — | 589,854 | 2,081,820 | — | 270,340 | 2,352,160 | 2,942,014 |
| Missouri | 737,410 | — | 737,410 | 460,830 | — | — | 460,830 | 1,198,240 |
| Ohio | 2,500 | 10,000 | 12,500 | — | — | — | — | 12,500 |
| Wisconsin[1] | 701,301 | 2,065 | 703,366 | 2,840,567 | 50,700 | 31,000 | 2,922,267 | 3,625,633 |
| **Regional Totals** | **8,520,738** | **27,305** | **8,548,043** | **15,980,141** | **13,029,075** | **367,140** | **29,376,356** | **37,924,399** |
| **Great Plains** | | | | | | | | |
| Kansas | — | 8,100 | 8,100 | — | 36,825 | — | 36,825 | 44,925 |
| Nebraska | 425,000 | 2,000 | 427,000 | 901,483 | 1,134,446 | — | 2,035,929 | 2,462,929 |
| North Dakota | 28,450 | 20,300 | 48,750 | 733,100 | 68,000 | — | 801,100 | 849,850 |
| South Dakota | — | — | — | — | — | — | — | — |
| Regional Totals | **453,450** | **30,400** | **483,850** | **1,634,583** | **1,239,271** | **0** | **2,873,854** | **3,357,704** |
| **Intermountain** | | | | | | | | |
| Arizona | — | — | — | — | — | — | — | — |
| Colorado | 21,800 | 5,166 | 26,966 | 8,275 | 71,976 | — | 80,251 | 107,217 |
| Idaho[1] | — | 11,797 | 11,797 | 2,249,019 | 4,704,632 | 4,910,555 | 11,864,206 | 11,876,003 |
| Montana[1] | 90,125 | 28,612 | 118,737 | — | 614,366 | 128,685 | 743,051 | 861,788 |
| Nevada | — | 1,318 | 1,318 | — | 174 | — | 174 | 1,492 |
| New Mexico | — | 20,684 | 20,684 | — | 75,000 | — | 75,000 | 95,684 |
| Utah | — | — | — | — | — | — | — | — |
| Wyoming | — | — | — | — | — | — | — | — |
| **Regional Totals** | **111,925** | **67,577** | **179,502** | **2,257,294** | **5,466,148** | **5,039,240** | **12,762,682** | **12,942,184** |
| **Alaska** | | | | | | | | |
| Alaska | — | — | — | — | — | 445,460 | — | 445,460 |
| **Pacific Northwest** | | | | | | | | |
| Oregon[1] | 3,505,300 | 927,675 | 4,432,975 | 39,091,958 | 34,211,403 | 3,802,375 | 77,105,736 | 81,538,711 |
| Washington[1] | 1,817,500 | 65,030 | 1,882,530 | 35,076,240 | 37,783,002 | 4,167,445 | 77,026,687 | 78,909,217 |
| **Regional Totals** | **5,322,800** | **992,705** | **6,315,505** | **74,168,198** | **71,994,405** | **7,969,820** | **154,132,423** | **160,447,928** |
| **Pacific Southwest** | | | | | | | | |
| California | — | 15,000 | 15,000 | 1,300,000 | 27,484,550 | — | 28,784,550 | 28,799,550 |
| Hawaii | — | 10,000 | 10,000 | — | 200 | — | 200 | 10,200 |
| **Regional Totals** | — | **25,000** | **25,000** | **1,300,000** | **27,484,750** | **0** | **28,784,750** | **28,809,750** |
| **Totals** | **42,617,388** | **1,732,012** | **44,349,400** | **965,517,587** | **406,747,593** | **18,212,120** | **1,390,031,840** | **1,439,126,700** |

[1]Totals include an estimate of container conifers produced in Canada; bareroot imports for Maine and containers for other States.

Table 2. Estimated hardwood and conifer tree seedling acres planted for each State and each region during the 2022 planting year.

| State | Hardwood acres planted[1] | Conifer acres planted[1] | Total acres planted[1] | FIA estimated acres planted[9] |
|---|---|---|---|---|
| **Southeast** | | | | |
| Florida[2] | 2,129 | 75,635 | 77,764 | 150,006 |
| Georgia[2] | 9,816 | 614,472 | 624,288 | 212,353 |
| North Carolina[2] | 678 | 126,096 | 126,775 | 108,401 |
| South Carolina[2] | — | 400,402 | 400,402 | 88,362 |
| Virginia[2] | 2,051 | 48,156 | 50,207 | 57,031 |
| **Regional Totals** | **14,675** | **1,264,761** | **1,279,435** | **616,153** |
| **South Central** | | | | |
| Alabama[2] | 6,707 | 301,794 | 308,501 | 218,748 |
| Arkansas[2] | 21,245 | 167,796 | 189,042 | 89,136 |
| Kentucky[3] | 1,078 | 143 | 1,222 | 1,142 |
| Louisiana[2] | — | 83,105 | 83,105 | 160,561 |
| Mississippi[2] | 324 | 146,455 | 146,778 | 140,495 |
| Oklahoma[2] | 1,109 | 6,645 | 7,755 | 31,659 |
| Tennessee[2] | 3,935 | 3,773 | 7,707 | 24,386 |
| Texas[2] | — | 125,035 | 125,035 | 126,044 |
| **Regional Totals** | **34,398** | **834,746** | **869,144** | **792,171** |
| **Northeast** | | | | |
| Connecticut[3] | — | — | — | — |
| Delaware[2] | — | — | — | 515 |
| Maine[5] | 9 | 7,173 | 7,182 | 4,069 |
| Maryland[2] | 2,369 | 1,740 | 4,109 | — |
| Massachusetts[3] | 1 | — | 1 | — |
| New Hampshire[3] | 43 | 798 | 841 | 402 |
| New Jersey[3] | 117 | 27 | 145 | — |
| New York[5] | 415 | 589 | 1,005 | 2,077 |
| Pennsylvania[3] | 693 | 2,941 | 3,634 | 1,847 |
| Rhode Island | — | — | — | — |
| Vermont[3] | 6 | 277 | 282 | — |
| West Virginia[3] | — | — | — | — |
| **Regional Totals** | **3,653** | **13,545** | **17,198** | **8,910** |
| **North Central** | | | | |
| Illinois[3] | 1,868 | 228 | 2,096 | 1,667 |
| Indiana[4] | 2,846 | 1,114 | 3,959 | 2,413 |
| Iowa[5] | 1,074 | 276 | 1,351 | — |
| Michigan[2] | 5,814 | 41,186 | 47,000 | 6,330 |
| Minnesota[2] | 1,072 | 4,277 | 5,349 | 8,403 |
| Missouri[3] | 1,695 | 1,059 | 2,755 | 223 |
| Ohio[3] | 29 | — | 29 | 2,173 |
| Wisconsin[6] | 879 | 3,653 | 4,532 | 8,256 |
| **Regional Totals** | **15,278** | **51,793** | **67,071** | **29,465** |

Table 2 *(continued)*. Estimated hardwood and conifer tree seedling acres planted for each State and each region during the 2022 planting year.

| State | Hardwood acres planted[1] | Conifer acres planted[1] | Total acres planted[1] | FIA estimated acres planted[9] |
|---|---|---|---|---|
| **Great Plains** | | | | |
| Kansas[2] | 15 | 67 | 82 | 1,012 |
| Nebraska[2] | 776 | 3,702 | 4,478 | — |
| North Dakota[2] | 89 | 1,457 | 1,545 | — |
| South Dakota[2] | — | — | — | 164 |
| **Regional Totals** | **880** | **5,225** | **6,105** | **1,176** |
| **Intermountain** | | | | |
| Arizona[2] | — | — | — | — |
| Colorado[2] | 49 | 146 | 195 | 669 |
| Idaho[2] | 21 | 21,571 | 21,593 | 10,016 |
| Montana[2] | 216 | 1,351 | 1,567 | 4,506 |
| Nevada[2] | 2 | — | 3 | — |
| New Mexico[2] | 38 | 136 | 174 | — |
| Utah[2] | — | — | — | — |
| Wyoming | — | — | — | 846 |
| **Regional Totals** | **326** | **23,205** | **23,531** | **16,037** |
| **Alaska** | | | | |
| Alaska[2] | — | 810 | 810 | — |
| **Pacific Northwest** | | | | |
| Oregon[7] | 12,666 | 220,302 | 232,968 | 118,350 |
| Washington[7] | 5,379 | 220,076 | 225,455 | 96,376 |
| **Regional Totals** | **18,044** | **440,378** | **458,423** | **214,726** |
| **Pacific Southwest** | | | | |
| California[8] | 33 | 63,966 | 63,999 | 36,986 |
| Hawaii[8] | 22 | — | 23 | 568 |
| **Regional Totals** | **56** | **63,966** | **64,022** | **37,554** |
| **TOTALS** | **87,310** | **2,698,429** | **2,785,739** | **1,716,192** |

[1] Acres planted were estimated assuming:
[2] 550 stems/acre.
[3] 435 stems/acre.
[4] 650 stems/acre.
[5] 600 stems/acre.
[6] 800 stems/acre.
[7] 350 stems/acre.
[8] 450 stems/acre.
[9] FIA = Forest Inventory and Analysis; average annual acreage planted estimated for all States on 5-year cycles, except for Alabama, Louisiana, Mississippi, and North Carolina, which are on 7-year cycles, and for Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, and Washington, which are on 10-year cycles. Data generated by Andy Hartsell, USDA Forest Service.

## Assumptions

The following assumptions were used in compiling this report.

1. *The number of seedlings reported by the participating forest and conservation nurseries was the number of shippable seedlings produced for distribution in the 2022 planting season (i.e., seedlings that were planted from fall of 2021 through spring of 2022).*

Some species of forest seedlings require two or more growing seasons to reach accepted forest and conservation seedling size standards, so not all seedlings in production at a nursery at any given time are considered shippable (i.e., available for distribution). Therefore, only shippable seedlings were counted.

2. *All seedling production reported in this survey met the grading standards for the respective nurseries (i.e., cull seedlings were not included in the estimates).*

Production estimates are often based on seedbed inventories of seedlings meeting grading standards. For cases in which nurseries ship seedlings by weight, as opposed to examining and counting each seedling, landowners and tree planters often plant every seedling that is shipped to them.

3. *Seedling production data were collected from all the major nurseries that produced forest and conservation tree seedlings for the planting season.*

Considerable effort was made to contact all major producers of forest and conservation seedlings (private, State, Federal, Tribal). The universities collecting the survey data reported, with few exceptions, that the major producers were included in the results.

4. *All seedlings reported in this survey were produced for reforestation and conservation projects.*

Some of the nurseries that participated in this survey also produce seedlings for ornamental use, Christmas tree production, or other horticultural purposes. Private nurseries were asked to report only seedling production destined for conservation and reforestation planting.

5. *Forest tree seedlings remain in the general area where they are produced.*

Forest and conservation seedlings are routinely shipped across State borders and at times across international borders. It is assumed that, on average, the number of seedlings imported into a State is equal to the number of seedlings exported from that State. In some States, a significant number of seedlings are produced in Canada and imported for planting in those States. Estimates of the number of seedlings shipped from Canada were obtained from Canadian nurseries that routinely export seedlings to the United States.

6. *Dividing the number of seedlings shipped from forest and conservation nurseries by the average number of stems planted per acre in a specific State is an appropriate proxy of the number of acres of trees planted during the planting season (table 2).*

These estimations do not include direct seeding or natural forest regeneration activities. Average tree planting densities for each State were provided by FIA.

7. *Respondents to the production survey reported only hardwood and conifer trees produced.*

Nurseries were asked not to include shrubs in their production estimates. Many conservation and restoration plantings include shrubs and herbaceous plants to address wildlife, biodiversity, or other management objectives. Using only tree production to estimate acres planted results in an underestimate of planted acreage where a mixed planting of shrubs and trees occurred.

## Data Trends

More than 1.4 billion forest tree seedlings were planted in the United States in fiscal year 2022, an increase of approximately 3 percent from fiscal year 2021 and 10 percent higher than the 10-year average (figure 1). The increase is attributable, in part, to a resumption of near-normal operations following the coronavirus pandemic. Seedling production in the Southern United States has increased annually from 2012 through 2022 (figure 2). In the Eastern United States, seedling production generally declined from 2012 to 2020, but was 13 percent higher in 2022 compared with 2020 (figure 2). In the Western United States, production has fluctuated over time (figure 2) but increased 30 percent between 2020 and 2022 due to increases in reforestation after years of wildfire. Some of the year-to-year variation is attributed to inconsistent participation from

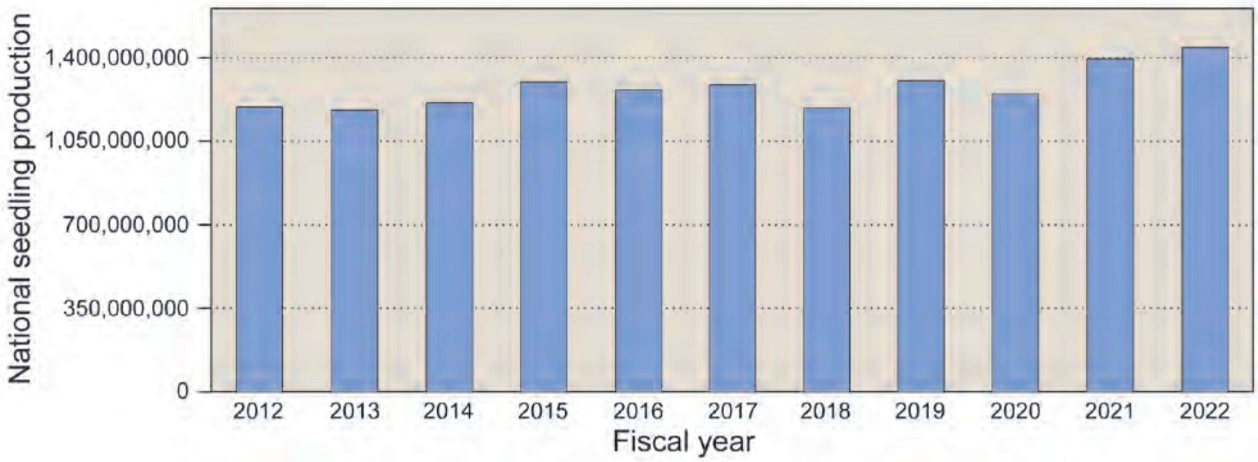


**Figure 1.** Total annual forest nursery seedling production in the United States for fiscal years 2012 through 2022. Sources: this report, Haase et al. (2019, 2020, 2021, 2022), Harper et al. (2013, 2014), Hernández et al. (2015, 2016, 2017, 2018)

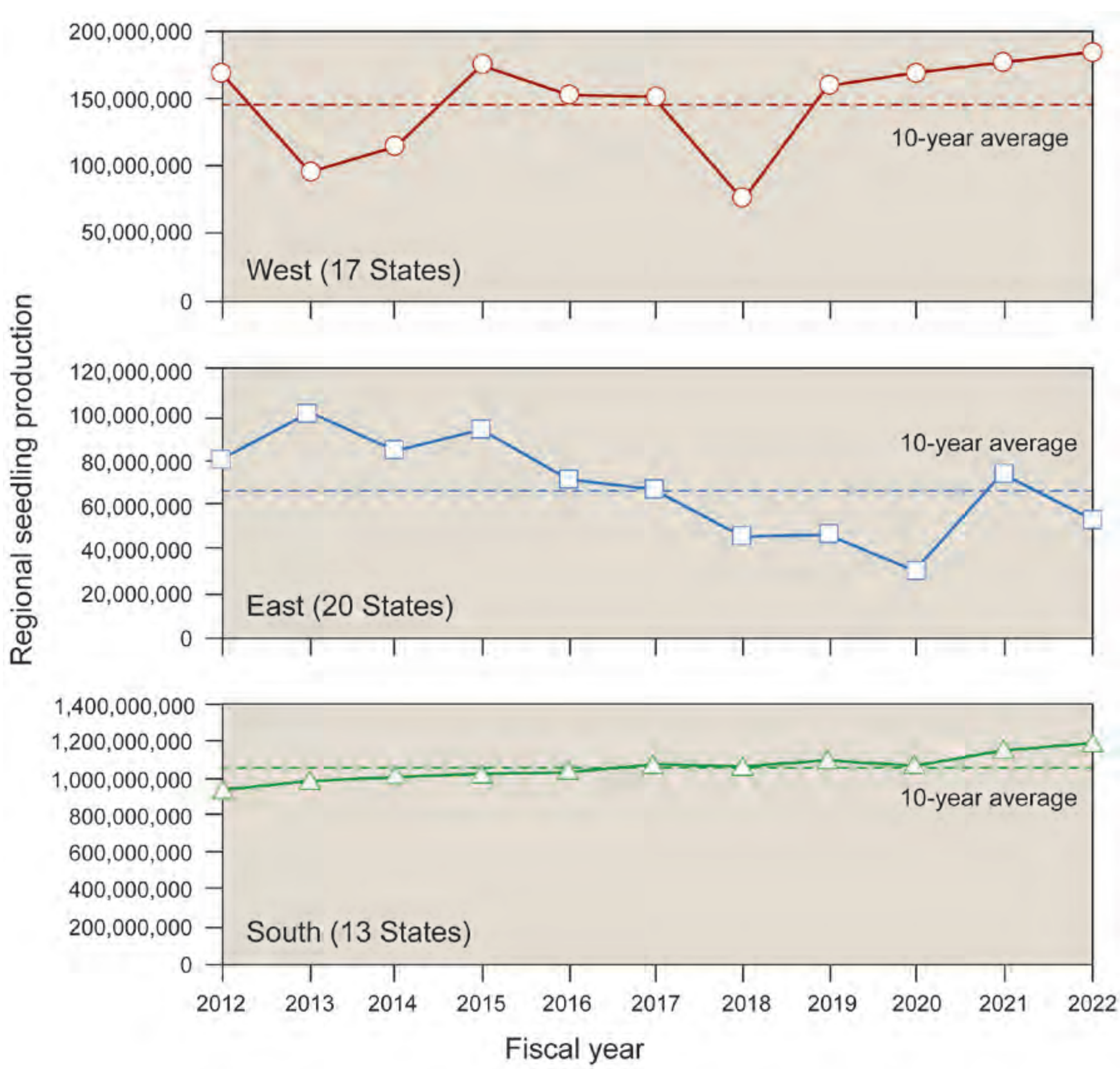


**Figure 2.** Annual forest nursery seedling production by region for fiscal years 2012 through 2022. Ten-year production averages are: 145,780,038 (west), 67,088,119 (east), and 1,068,908,254 (south). Sources: this report, Haase et al. (2019, 2020, 2021, 2022), Harper et al. (2013, 2014), Hernández et al. (2015, 2016, 2017, 2018)

nurseries during data collection and shifting planting needs following wildfires, pests, and harvests. Based on the total number of seedlings shipped and the average number of seedlings planted per acre in each State, nearly 2.8 million ac (1,127,348 ha) of tree seedlings were planted during the fall 2021 through spring 2022 planting season.

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