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)

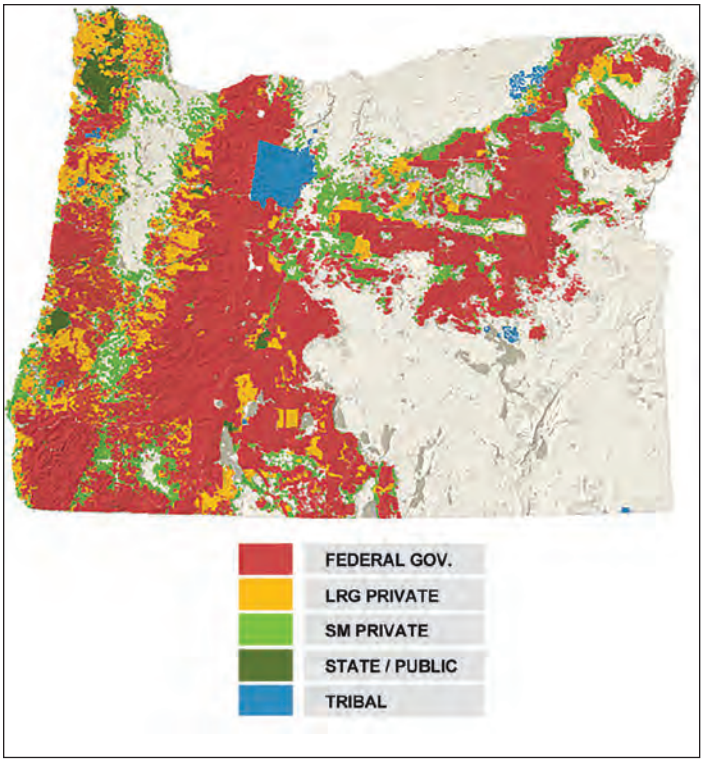

Figure 2. The majority (64 percent) of Oregon forests are owned by Federal agencies. (Source: Oregon Department of Forestry)

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).

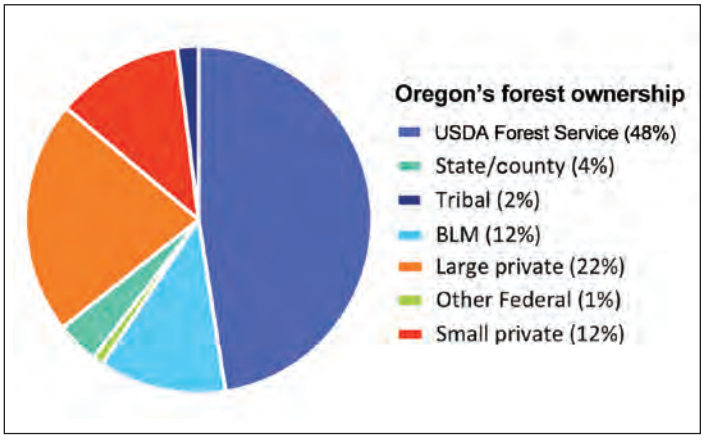

Figure 3. Oregon forests are owned by Federal, large private, small private, State/county, and Tribal entities. (Adapted from Oregon Forest Resources Institute, 2018)

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

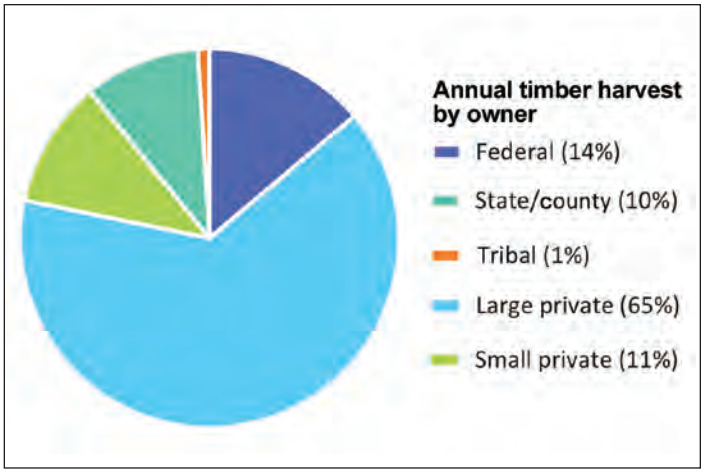

Figure 4. Private timberlands account for 75 percent of the annual timber volume currently harvested in Oregon. (Adapted from Oregon Forest Resources Institute, 2020)

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 in-

clude 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).

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).

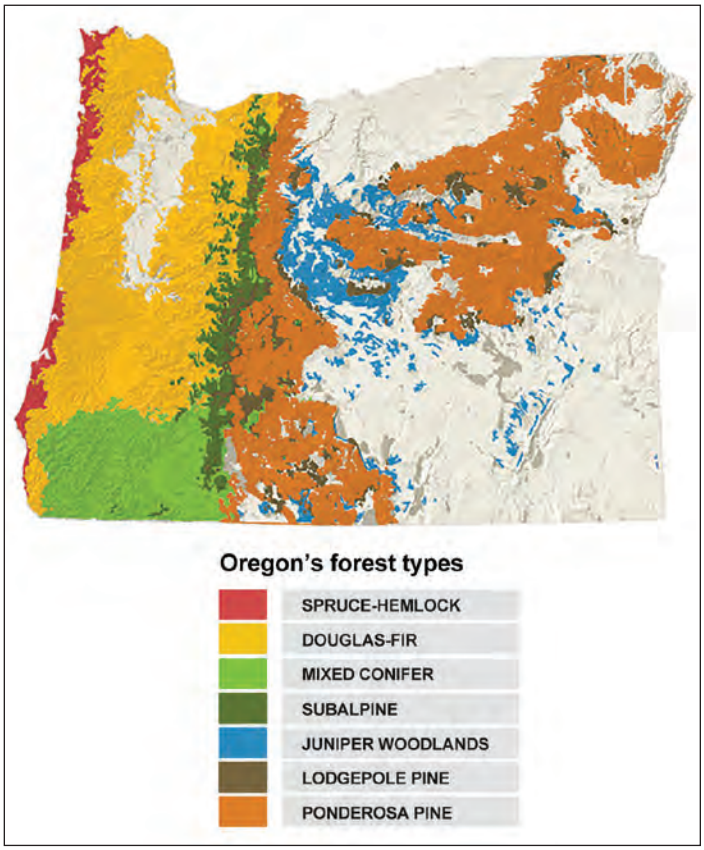

Figure 7. Oregon is home to some of the world's most productive forests, dominated by Douglas-fir on the west side of the Cascades. (Source: Oregon Forest Resources Institute, 2017)

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

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 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).

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)

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

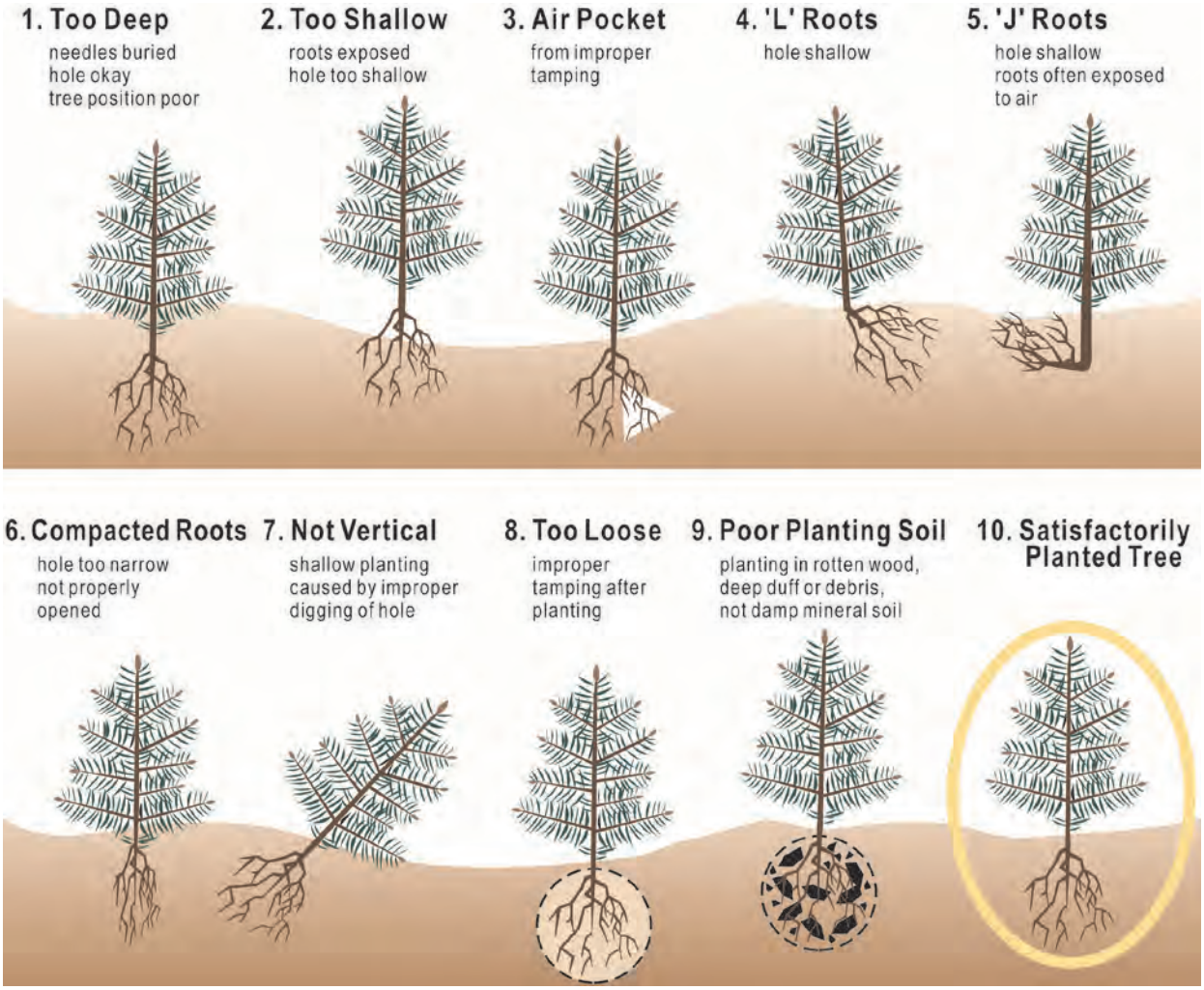

Figure 21. There is one proper way, and many improper ways, to plant seedlings. (Adapted from Rose and Haase, 2006)

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.

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REFERENCES

Campbell, S.; Azuma, D.; Weyermann, D. 2004. Forests of western Oregon: an overview. PNW-GTR-525. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 27 p.

Cloughesy, M.; Woodward, J. 2018. Oregon's forest protection laws: an illustrated manual. 3rd ed. Portland, OR: Oregon Forest Resources Institute. 222 p.

Dumroese, R.K.; Landis, T.D.; Pinto, J.R.; Haase, D.L.; Wilkinson, K.W.; Davis, A.S. 2016. Meeting forest restoration challenges: using the target plant concept. Reforesta. 1: 37–52. https://doi.org/10.21750/REFOR.1.03.3.

Fargione, J.; Haase, D.L.; Burney, O.T.; Kildisheva, O.A.; Edge, G.; Cook-Patton, S.C.; Chapman, T.; Rempel, A.; Hurteau, M.D.; Davis, K.T.; Dobrowski, S.; Enebak, S.; De La Torre, R.; Bhuta, A.A.R.; Cubbage, F.; Kittler, B.; Zhang, D.; Guldin, R.W. 2021. Challenges to the reforestation pipeline in the United States. Frontiers in Forests and Global Change. 4: 629198. https://doi.org/10.3389/ffgc.2021.629198.

Fitzgerald, S.A. 2008. Successful reforestation: an overview. The Woodland Workbook. EC 1498. Corvallis, OR: Oregon State University. 8 p.

Gale, C.B.; Keegan, C.E., III; Berg, E.C.; Daniels, J.; Christensen, G.A.; Sorenson, C.B.; Morgan, T.A.; Polzin, P. 2012. Oregon's forest products industry and timber harvest, 2008: industry trends and impacts of the Great Recession through 2010. Gen. Tech. Rep. PNW-GTR-868. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 55 p. https://doi.org/10.2737/PNW-GTR-868.

Haase, D.L.; Pike, C.; Enebak, S.; Mackey, L.; Ma, Z.; Silva, C.; Warren, J. 2022. Forest nursery seedling production in the United States – fiscal year 2021. Tree Planters' Notes. 65(2): 79–86.

Jensen, E.C. 2020. Trees to know in Oregon and Washington. EC 1450. 70th Anniversary Edition. Corvallis, OR: Oregon State University. 172 p.

LaLande, J. 2022. U.S. Bureau of Land Management. Portland, OR: Oregon Encyclopedia, Oregon Historical Society. https://www.oregonencyclopedia.org/articles/u_s_bureau_of_land_management/. (June 2023)

Magalska, L.; Cohen, E.; Deisenhofer, F.; Drake, T.; Barker, D.; Patton, S.; Banks, M.; Gourley, M. 2022. Cooperative Long-Term Production Forestry Research in the PNW. Draft. Unpublished draft.

Oester, P.T.; Fitzgerald, S.A.; Strong, N.A.; Parker, R.; Henderson, L.V.; Deboodt, T.; Emmingham, W.H.; Filip, G.M.; Edge, W.D. 2018. Reforestation methods and vegetation control. In: Ecology and management of Eastern Oregon forests. Manual 12. Corvallis, OR: Oregon State University: 125–140. Chapter 6.

Oregon Department of Geology and Mineral Industries. 2009. Oregon: A geologic history. https://www.oregongeology.org/pubs/ims/ims-028/index.htm. (March 2023)

Oregon Department of Forestry, Forest Resources Division. 2022. Sources of native forest nursery seedlings. 27 p. https://www.oregon.gov/odf/documents/workingforests/seedling-catalog.pdf. (March 2023)

Oregon Forest Laws. 2023. Private Forest Accord. https://oregonforestlaws.org/private-forest-accord. (April 2023)

Oregon Forest Resources Institute. 2019. Oregon's forest economy: 2019 forest report. Portland, OR: Oregon Forest Resources Institute. 12 p.

Oregon Forest Resources Institute. 2020. Establishing and Managing Forest Trees in Western Oregon. 36 p. https://oregonforests.org/pub/establishing-and-managing-forest-trees-western-oregon. (March 2023)

Oregon Forest Resources Institute. 2023a. About OFRI. https://oregonforests.org/about-ofri. (April 2023)

Oregon Forest Resources Institute. 2023b. Forest basics: history. https://oregonforests.org/history. (February 2023)

Oregon Forest Resources Institute. 2023c. Forest management: forest laws. https://oregonforests.org/forest-laws. (February 2023)

Oregon Forest Resources Institute. 2023d. Oregon forest facts: 2023-24 edition. https://oregonforests.org/sites/default/files/2023-01/OFRI_2023ForestFacts_WebFinal.pdf. (March 2023)

Oregon State Legislature. 1971. Oregon Forest Practices Act. ORS 527.545 [1991 c.919 §6; 1993 c.562 §1; 1995 s.s. c.3 §39c; 1996 c.9 §5; 2012 c.56 §5]. https://www.oregonlegislature.gov/bills_laws/ors/ors527.html. (March 2023)

Rahe, M.L. 2018. Estimates of migrant and seasonal farmworkers in agriculture, 2018 update and technical appendix. Portland, OR: Oregon Health Authority, Public Health Division, Health Policy, and Analysis Division. 36 p.

Rasmussen, M.; Lord, R.; Fay, R.; Baribault, T.; Goodnow, R. 2021. 2020 Labor Day fires: economic impacts to Oregon's forest sector. Portland, OR: Oregon Forest Resources Institute. 104 p. https://oregonforests.org/pub/2020-labor-day-fires-economic-impacts. (March 2023)

Rose, R.; Haase, D.L. 2006. Guide to reforestation in Oregon. Corvallis, OR: College of Forestry, Oregon State University. 48 p.

State of Oregon. Oregon Legislative Assembly history. 2023. https://sos.oregon.gov/archives/Pages/records/legislative-records-guide-history.aspx. (February 2023)

Trobaugh, J. 2012. Forest seedling planting in Washington State. Tree Planters' Notes. 55(1): 4–11.

Withrow-Robinson, B.; Bennett, M.; Ahrens, G. 2011. A guide to riparian tree and shrub planting in the Willamette Valley: steps to success. EM 9040. Corvallis, OR: Oregon State University. 28 p.