Outplanting Seedlings in the Pacific Northwest: Historical Efforts and Contemporary Constraints to Success

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Abstract

As incidence of wildfires increase across the Western United States and world leaders call for the implementation of tree-planting programs to mitigate the effects of climate change, the demand for tree seedlings has surpassed current nursery capacity. Reforestation goals cannot be met, however, by increasing nursery capacity alone. Outplanting capacity must be scaled simultaneously with increasing seedling production. Once seedlings leave the nursery to be outplanted, their survival is dependent on a number of factors, including expertly timed site preparation, storage and transport specifications, timing and logistics for seedling delivery, labor availability, planting method, and the interaction between the planting prescription and biophysical conditions onsite. Building a greater understanding of historical and current outplanting practices as a social framing of current outplanting capacity may be useful as the industry prepares for surges in financial resources for improving the reforestation pipeline. This article examines the components of the outplanting process based on literature reviews, interviews with foresters, planting crew foremen, planters, and field observations during planting events throughout the Pacific Northwest. Results indicate that current outplanting practices have changed very little in the last 80 years, yet planting outputs are increasingly expected to meet growing reforestation demands. Planters are limited by myriad species and stock types, tool types, and elevation ranges. To improve future outplanting operations, innovating in tools and equipment to reduce the burden of labor is critical, along with addressing the issue of sourcing and supporting future labor pools with the appropriate infrastructure to expand the outplanting pipeline. This paper was presented at The Reforestation Pipeline in the Western United States–Joint Annual Meeting of the Western Forest and Conservation Nursery Association, the Intertribal Nursery Council, and the Intermountain Container Seedling Growers Association (Missoula, MT, September 27–29, 2022).

Introduction

The demand for reforestation in the United States is growing. A recent national analysis found that 64 million acres of natural lands have the potential for artificial regeneration investment (Fargione et al. 2021). Of this, 25 million acres are in the Western United States with about 6.5 million acres in the Pacific Northwest (California, Idaho, Oregon, Washington). Reforestation programs are receiving increased Federal support via legislation such as the Repairing Existing Public Land by Adding Necessary Trees (REPLANT) Act, which expands funding towards reforestation on National Forest System (NFS) lands managed by the U.S. Department of Agriculture (USDA) Forest Service (United States Senate Committee on Agriculture, Nutrition, and Forestry 2021). The Biological the Infrastructure Investment and Jobs Act (IIJA) and Bipartisan Infrastructure Law (BIL) extend beyond NFS lands to increase funds for nursery and reforestation infrastructure needs on Tribal, State, and other public lands (Balloffet and Dumroese 2022, Parajuli 2022). In addition, the Inflation Reduction Act (IRA) increases the tree-planting budget for private and urban forestland (Federal Register 2022, Sustainable Forestry Initiative 2022). To meet the ambitious reforestation targets proposed by myriad scientists and political figures, and supported by the public, each component of the reforestation pipeline (i.e., seed, nurseries, outplanting, and post-planting care) must be thoroughly assessed and then proportionally improved (Fargione et al. 2021). Ultimately, the potency of the reforestation pipeline will be dependent on the collective ability to successfully address each of these components to meet current and future demands.

A Look Back

Historically, resources were invested into advancing outplanting capabilities in response to societal needs (e.g., wildfire recovery and employment programs of the early 1900s) and later in response to shifting forest management practices among the commercial forestry sector for plantation management (Taylor 1948). In the early 1900s, forest loss and ecosystem degradation were of paramount concern due to increasing occurrence of wildfires and largely unregulated timber harvesting. Artificial regeneration practices gained traction during the last century as landowners sought to exert more control of their forest resources (e.g., stand density, species, stock type, etc.) by growing and planting seedlings (Curtis et al. 2007, Taylor 1948). As a result, several nurseries were established that were either directly supporting the timber industry or producing tree seedlings for a combination of local horticultural and forestry needs. Large timber companies opened their own nurseries to have a supply of seedlings for more sustainable management of their timberlands. In addition, the USDA Forest Service established nurseries around the country including the Wind River Nursery (Washington), Monument Nursery (Colorado), and Savenac Nursery (Montana) in the Western United States (Curtis et al. 2007, Donoghue 1982, Dumroese et al. 2005).

Federal programs also supported mass reforestation efforts by establishing subsidized tree-planting operations. For example, one of the functions of the Civilian Conservation Corps (CCC) was to address forest-management concerns and curb unemployment caused by the Great Depression (Dumroese et al. 2005, Maher 2008, Otis et al. 1986, Paige 1985, Throop 1979). The CCC was comprised predominantly of young men incentivized with wages, benefits (e.g., free meals, lodging, medical care, and dental care), and support infrastructure (e.g., barracks, mess hall, bath house, classrooms, and hospital) (figure 1) (Paige 1985). The CCC and their planting operations functioned from 1933 to 1941 under a strict hierarchy reflective of the military chain of command and facilitated intensive labor that helped to meet the reforestation goals of the time (Paige 1985).

From the 1940s onward, forest nursery technology and the corresponding outplanting programs evolved to improve seedling quality and subsequent outplanting performance for a variety of planting environments using science-based approaches (Curtis et al. 2007, Haynes 2003, Sharp 1949). Nurseries worked to provide seedlings of known source with consistent materials and packing specifications using best management practices to meet seasonal demands across a diversity of ecosystems. With standardizations and stock type specifications, foresters grew more adept at prescribing the appropriate artificial regeneration strategy to a given outplanting site. The parallel maturation of these nursery and outplanting programs revealed an opportunity to further refine artificial regeneration by constructing formal processes for feedback loops and improvements. This process came to fruition with the introduction of the Target Seedling Concept (TSC) in 1990 to link seedling morphological and physiological quality with subsequent outplanting success (Rose et al. 1990). When applied to the reforestation pipeline, the TSC provides a feedback loop between nursery and client to accommodate varied ecoregions and multifaceted reforestation efforts (Dumroese et al. 2016).

Despite the significant advancements in nursery production and site preparation techniques to support outplanting efforts, the physical process for outplanting seedlings has largely remained the same, with improvements isolated to introductions of various tools such as the Pottiputki developed in Finland (BCC, Sweden) and the planting gun developed in Canada (Walters 1963). Otherwise, the most common planting tools are the planting shovel, planting hoe, planting bar, and dibble (table 1) (Elfritz et al. 2006, Haywood et al. 2013, Kloetzel 2004, Missoula Technology and Development Center 2013). Although tractors and other machinery (e.g., continuous furrow planters and intermittent planters) have been used for decades to outplant seedlings in the Great Plains and the Eastern United States (Barnett 1974, Stoeckeler and Slabaugh 1965), they are seldom used for reforestation in the Western States because of rocky soils, steep slopes, and remote locations. The long-term reliance on manual labor via tree planting

Figure 1. (a) Strictly organized planting by CCC crews resulted in high productivity on tree planting projects and other forest management responsibilities. In such a rigorous structure, crews were incentivized with support infrastructure, such as (b) barracks, (c) dining facilities, and classrooms. (Photos from Museum of North Idaho: CCC-7-37, FS-13-033, CCC-4-10)

crews for outplanting tree seedlings in the Western United States has also been influenced by associated costs, such as equipment, seed, seedlings, transportation, lodging, etc. (Dumroese et al. 2016, Granzow et al. 2018, Kloetzel 2004).

Current Practices

Today, the confluence of climate-driven disturbance events (i.e., increased wildfire risk, drought, and altered precipitation patterns) and legislation to support healthy and resilient forests is once again driving innovations in forest management practices, such as reforestation, through an unprecedented expansion of tree planting efforts (Fargione et al. 2021, Grossnickle and MacDonald 2021, Keenan 2015, Parks and Abatzoglou 2020). To approach the backlog of acreage in the country that requires reforestation and to reach reforestation targets proposed by Fargione et al. (2021), seedling production in the United States must increase from its current estimated national production of approximately 1.4 billion seedlings annually (Haase et al. 2022) to approximately 4 billion seedlings annually. This expansion in seedling production justifies the provision for increased capacity and innovation of outplanting practices. To achieve these targets requires addressing labor shortages, seasonal shifts in planting and sowing timelines, and lackluster or outdated nursery and planting infrastructure (Grossnickle and MacDonald 2021).

Implementing the new, proposed planting regimes will be challenging. Labor shortages are the single greatest challenge that must be overcome to meet current reforestation goals (Fargione et al. 2021, Trobaugh 2018). Currently, approximately 82 percent of the forestry industry's labor force consists of temporary H-2B-certified employees (Bier 2021)

Table 1. Description and utility of historical and current tools used in seedling outplanting.

				
Tools	Hoedad, Rindt, Mattock, Narrow Blade (plug), Swedish, Wifsta	OST Bar, KBC Bar, Planting Spear	Planting Shovel, Round-point Shovel, Garden Shovel	Dibble Bar
Average cost	$45	$25–35	$20–25	$46–66
Planting rate (trees per day)	800–1,000	350–400	24–350	160–2,000
Stock type(s)	Bareroot and container	Bareroot and container	Bareroot and container, larger seedlings	Small bareroot and container
Weight range (lbs)	3.0–7.5	8.0–10.0	~2.0–7.0	~8.0
Planting utilities	• Used for scalping and creating planting holes • Varied blade angles, 90 to 100°, depending on slope and site conditions • Lightweight, tough, easy to handle • Versatile and inexpensive • Effective in steep terrain, rocky or clay soils, heavy brush, or slash	• Common tool for planting in hard, rocky soils with roots • Simple, inexpensive, and versatile • Less fatigue on operators • Used in confined spaces, on steep slopes, or rocky ground	• Produces large planting holes primarily for seedlings with large root systems • Ability to maximize soil displacement • Easy use for inexperienced planters • Well suited for planting in areas where high survival rates are crucial • Most effective in deep, loose soils	• Fast hand tool • Creates small holes • Effective in loose soils

Table 1 continued on next page

Table 1 ***continued.*** Description and utility of historical and current tools used in seedling outplanting.

				
Tools	Hand auger, power auger	Hammer-action hand planter	Adze hoes, duty scalping tool, American eye hoe, Pulaski, McLeod, Pickmattock	Pottiputki
Average cost	$600–2,000	$675–1,000	$20–30	$255-265
Planting rate (trees per day)	400–750	280–480	80	N/A
Stock type(s)	Bareroot (including large sizes) and container	Bareroot and container	Container, including large sizes	Container
Weight range (lbs)	~7.0–14.0	11.0 –22.0	~3.0–7.5	~5.5–8.0
Planting utilities	• Creates holes for large seedlings • Beneficial for cutting thick roots (~0.38 in) • Creates holes quickly and consistently without compression • Best for shallow soil or sites with harsh conditions • Used primarily in loamy, sandy, or pumice soils	• Designed for rocky soils • Withstands significant wear and tear	• Removes forest litter and competitive vegetation • Lightweight and simple to use • Quick and effective for site preparation	• Ergonomically beneficial • Increases efficiency • Has depth and angle precision

Photos by Gabriel Altieri (hoedad, planting bars, dibble, and auger), Matthew Aghai (shovel), Paul Aston, Aston MTB, Ltd. (scalper), Hallman (1991) (hammer-action), and BCC Plant the Planet (Pottiputki).

composed of guest and migrant workers from Latin America. While the H-2B visa program is a key asset to providing labor to the forestry sector, the program is hampered by a number of drawbacks. In 2022, only 66,000 visas were obtainable through application, with 33,000 visa applications being accepted at either half of the fiscal year. During the past 17 years, the estimated count of H-2B-certified positions has been cut by more than half: 24,650 were accepted in 2004, whereas only 11,117 were accepted in 2020 (Bier 2021). The demand for H-2B visas is projected to rise in the near term as reforestation efforts across sectors and ownerships increase. In addition to concerns regarding H-2B visa shortages, some organizations have rigid hiring practices requiring them to hire locally, within their Tribe, or to outsource labor elsewhere. A diminishing supply of reliable labor may prove to be challenging for these groups as they look to increase planting operations in the future.

As important as it is to build upon labor pools, retention of the current workforce is equally important. Compared with the array of benefits and incentives historically provided to the CCC planters, tree planters today receive less total compensation (i.e., wages, benefits, and support infrastructure). Tree planting is often externalized to contractors who bid and compete for tree-planting contracts across industrial and agency ownerships. As a result, the incentive structure is designed around maximizing productivity at minimum cost. Thus, planters are predominantly paid on a per-tree, per-project, or per-acre basis and are often only provided with minimal equipment (e.g., shovel or hoedad and a planting bag), transportation to the site, and rudimentary lodging throughout the duration of their contract (figure 2). Incentives for crews from other labor pools, such as AmeriCorps crews, prison crews, and volunteer crews, are also lacking, resulting in consistently high turnover.

Planter retention is also highly affected by the physical strain of the work. Tree planters exert significant energy to meet production expectations (figure 3). In Canada, planters receive universal healthcare and occasionally have physical therapists on staff to ensure they mitigate the physical toll on their bodies. Tree planters can expend the caloric equivalent of two marathons per day (Granzow et al. 2019, Hodges and Kennedy 2011, Paarsch and Shearer 1997). In addition to cardiovascular stress, planters experience musculoskeletal disorders in the neck, shoulder, and lower back as a result of bent postures for prolonged periods of time, significant repetition of motions, and continuous forceful muscle exertion (Granzow et al. 2018, 2019). An average 8- to 14-hour workday includes responsibilities and activities outside of planting, such as training, transportation, and seedling loading and unloading (Hodges et al. 2005, Luke 2014). Additionally, the nature of the work limits breaks, which are often only at the beginning and end of the work period (Hodges et al. 2005).

Input from Practitioners Regarding Current Practices

Current outplanting practices can be improved by working directly with those who are directly involved with the process (e.g., foresters, foreman, planters,

Figure 2. (a) Current-day tree planters are often provided with (b) planting tools and planting bags, and occasionally gloves or other personal protective equipment. In some cases, however, planters are required to purchase their own equipment. (Photos by Gabriel Altieri 2022)

Figure 3. Tree planting is a laborious and strenuous task, requiring crew members to exert large amounts of energy. (Photo by Gabriel Altieri 2022)

land managers, etc.). An informal study tracked planting operations in real time using social research methods, scientific information, and anecdotal knowledge. We reached out to organizations in the forestry industry across the Western United States to conduct in-person and remote interviews, remote surveys, and to shadow the various elements of their outplanting operations. Interview and survey questions were based on the following topics:

- Project management and objectives
- Species and stock type(s)
- Pre-planting logistics
- General planting
- Planting crew communication
- Post-planting logistics
- Planting process
- Overall satisfaction
- Crew demography
- Hiring capacity

A literature review of current outplanting practices informed interview questions, which were tailored to specific audiences (land managers, foremen, planting crew members, or inspectors). We obtained complete datasets from eight of nine organizations via interview and site visits in Washington (n = 3), Oregon (n = 4), and Idaho (n = 1) (figure 4). Each organization was classified as either Federal (2), Private (n = 4), or Tribal (n = 2). After the remote and in-person interviews were completed, follow-up questions were sent to each organization as needed.

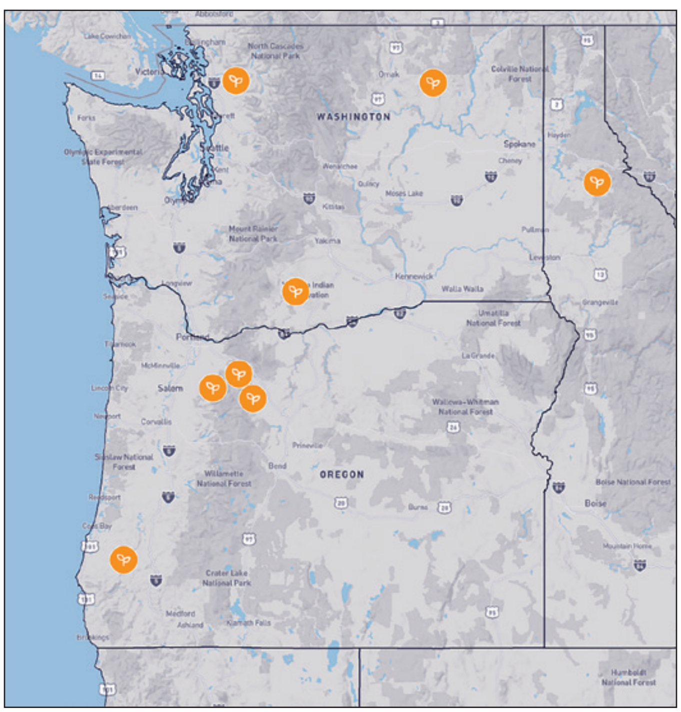

Figure 4. The study included site visits and surveys with organizations (orange markers) performing reforestation in Washington, Oregon, and Idaho, March through July 2022.

Data collection ran from March through July 2022. The approach was limited to capturing information surrounding spring outplanting efforts and was geographically constrained to the Pacific Northwest. While there is merit in collecting data throughout the autumn and winter outplanting seasons, most operations are contingent upon moisture availability, either as snow melt or rain, and the ability of nurseries to ensure seedling stock is prepared. Therefore, the most opportune time to collect data in the Pacific Northwest was during the spring planting season.

Before conducting interviews, we requested and received consent to take notes, collect data, and record both handwritten and electronic information. In-person site visits occurred whenever possible. These visits lasted approximately 1 full workday and involved facility tours, meetings with foresters tasked with managing seedling outplanting operations, shadowing and interviewing crew members involved with planting operations, meeting with inspectors, and capturing images. If the study team was unable to observe onsite operations, they conducted remote interviews or sent remote surveys to those organizations.

The objectives for the eight participating organizations fell into four broad categories: reforestation post-disturbance (e.g., wildfire; n = 2), reforestation post-timber harvest (n = 3), reforestation post-fire and post-timber harvest (n = 2), and restoration planting (e.g., riparian planting, natural restoration; n = 3). The organizations plant several species (table 2), with ponderosa pine and Douglas-fir being the most common and container-grown seedlings the most widely used stock type. Tools correspond with stock type, terrain, and soil conditions (figure 5), with shovels as the preferred choice when soil is easy to access and hoedads preferred for sites with heavy brush requiring scalping to clear competing vegetation. Data collected from the eight organizations are summarized in table 3.

Of the interviewees/respondents, 63 percent planted trees at 10- by 10-ft spacing (250 trees per acre; TPA) as per Rose and Haase (2006). Other spacing options were determined based on microsite availability,

Table 2. Several species are planted in the Pacific Northwest by participating organizations in the study to examine current outplanting practices.

Common name	Species name
Cluster rose	*Rosa pisocarpa* A. Gray
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Dune willow	*Salix hookeriana* Barratt ex Hook.
Geyer's willow	*Salix geyeriana* Andersson
Grand fir	*Abies grandis* (Douglas ex D. Don) Lindl.
Lodgepole pine	*Pinus contorta* Douglas ex Loudon
Noble fir	*Abies procera* Rehder
Ponderosa pine	*Pinus ponderosa* Lawson & C. Lawson
Port Orford cedar	*Chamaecyparis lawsoniana* (A. Murray bis) Parl.
Red alder	*Alnus rubra* Bong.
Redosier dogwood	*Cornus sericea* L. ssp. *sericea*
Scouler's willow	*Salix scouleriana* Barratt ex Hook.
Sitka willow	*Salix sitchensis* Sanson ex Bong.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Western larch	*Larix occidentalis Nutt.*
Western mountain ash	*Sorbus sitchensis* M. Roem.
Western redcedar	*Thuja plicata* Donn ex D. Don
Western white pine	*Pinus monticola* Douglas ex D. Don

stocking density, site history, and project objectives. Overall, planting spacing varied from 6 by 6 ft (1,210 TPA) to 15 by 15 ft (194 TPA) per organization. Elevations across planting sites ranged from 400 ft to 9,400 ft. As elevation increased at corresponding planting projects, TPA decreased. Planting elevations and species selection were also based on one another to match the ecosystem requirements of these elevations. Based on terrain, site preparation, and slope conditions, the quantity of trees planted per person per day varied between 278 and 2,000.

Differences in organizational infrastructure, internal bureaucracy, and standards for engagement with contracts influenced stakeholders' costs. For instance, when interviewing Tribal groups compared with private groups, Tribal groups utilized a wider variation in spacing, reforested more acreage, and planted ~4.5 times more seedlings. Tribal groups also paid a 16-percent premium at $0.25 per seedling compared with $0.21 per seedling paid by private groups for contracted planters wages. Although Federal organizations have historically paid higher planting rates ($0.35 per seedling), there seems to be a shift in relative planting costs based on labor availability. One Tribe has recently increased pay compared with prior planting years

Table 3. Current outplanting practices in the Pacific Northwest vary among the eight participating organizations (one per row in the table) in the study to examine current outplanting practices.

Project objectives	Species	Stock type(s)	Tool(s)	Spacing (ft)	Elevation range (ft)	Average trees per acre
Reforestation post-timber harvest	*Pseudotsuga menziesii, Thuja plicata, Chamaecyparis lawsoniana*	Styroblock®, Plug+	Planting shovel, planting bag	10 by 10, microsite	500–3,200	300
Reforestation post-timber harvest	*Pseudotsuga menziesii, Thuja plicata, Tsuga heterophylla*	Plug+	Planting shovel, planting bag	8 by 8, 9 by 9, 10 by 10, microsite	400–1,100	413
Reforestation post-disturbance, restoration planting	*Pseudotsuga menziesii, Rosa pisocarpa, Salix geyeriana, Salix hookeriana, Salix scouleriana, Salix sitchensis, Cornus sericea*	Bareroot	Planting shovel, planting bag	6 by 6, 7 by 7, 8 by 8, 9 by 9, 10 by 10, 11 by 11, 12 by 12, microsite	2,000–9,400	295
Reforestation post-disturbance	*Pinus ponderosa, Pinus monticola, Larix occidentalis*	Styroblock®	Hoedad, planting bag	14 by 14, microsite	2,200–3,200	218
Reforestation post-disturbance	*Pseudotsuga menziesii, Pinus monticola, Thuja plicata, Tsuga heterophylla, Abies procera, Alnus rubra*	Bareroot, Styroblock®, Plug+	Hoedad, planting bag	13 by 13, 14 by 14, microsite	2,200–3,800	259
Reforestation post-timber harvest	*Pseudotsuga menziesii, Abies grandis, Pinus ponderosa, Pinus contorta, Larix occidentalis*	Bareroot, Styroblock®, Plug+	Hoedad, planting bag	8 by 8, 9 by 9, 10 by 10, 11 by 11, 12 by 12, microsite	3,411–4,885	300
Reforestation (post-fire and post-timber harvest), restoration planting	*Pseudotsuga menziesii, Pinus ponderosa*	Bareroot, Styroblock®, Plug+	Planting shovel, hoedad, Pottiputki, planting bag	8 by 8, 10 by 10, 12 by 12, microsite	2,400–2,900	400
Reforestation (post-fire and post-timber harvest), restoration planting	*Pseudotsuga menziesii, Pinus ponderosa, Larix occidentalis*	Styroblock®, Plug+	Planting shovel, planting bag	12 by 12, 13 by 13, 14 by 14, 15 by 15, microsite	2,500–5,000	200

Figure 5. Planters use a variety of hand tools, which vary by site conditions, stock type, soil type, and personal preference. Participants primarily used (a) hoedads and (b and c) planting shovels during planting operations observed in the study. (Photos by Gabriel Altieri and Matthew Aghai, 2022)

to accommodate their growing need for reforestation, increasing relative reforestation costs to $1.25 per seedling, which includes all aspects of the reforestation pipeline (e.g., seed sourcing, seedling production, site preparation, planting, and monitoring).

The most common challenges reported by the eight organizations were planting quality and handling (table 4). These issues include poor planting techniques (e.g., J-rooting, L-rooting, wasting or stashing trees, etc.) and improper handling during transportation (e.g., mismanagement of planting boxes, improper temperature regulation, etc). The second most common challenge was associated with terrain and site conditions and included problems with site preparation (e.g., budget or timing constraints) and planting difficulties because of site conditions (e.g., heavy brush, unfavorable soil conditions, and steep slopes). Some of these issues can be exacerbated by transportation distances (figure 6).

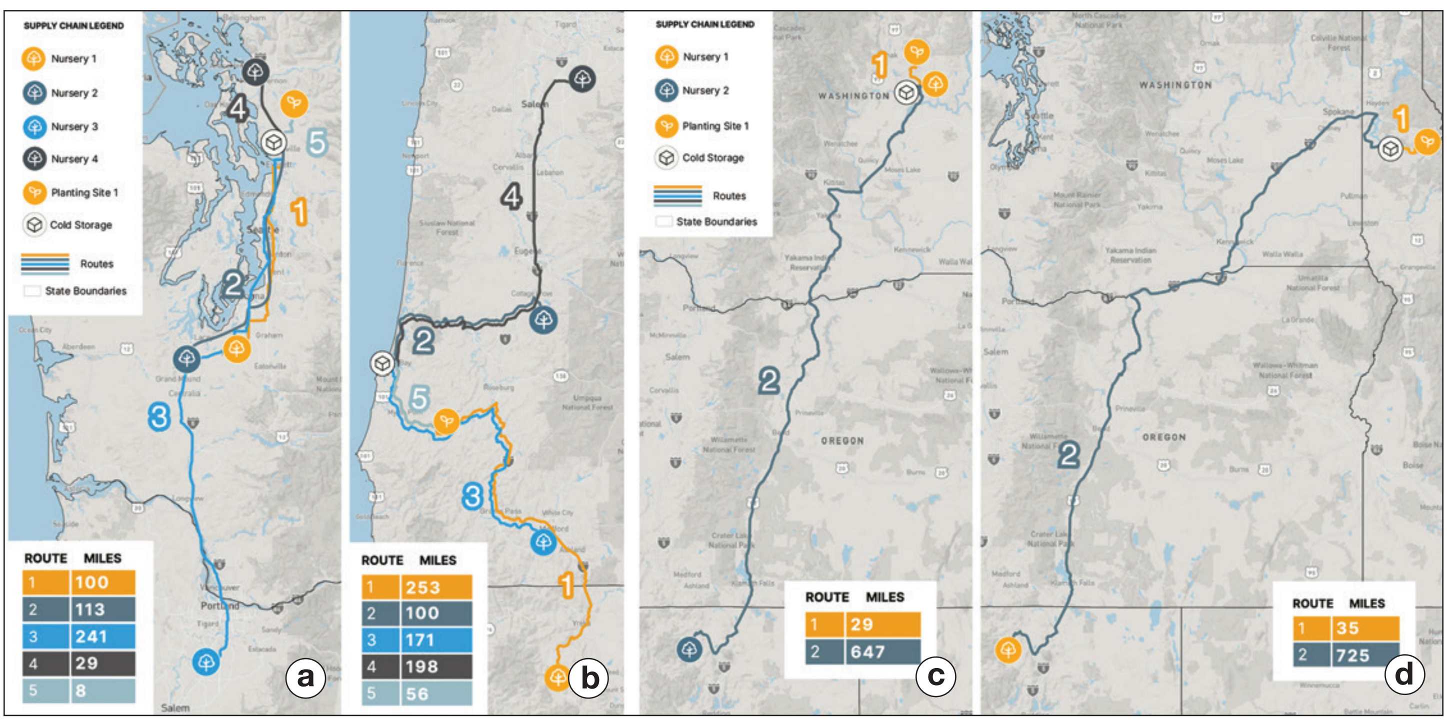

Figure 6. Seedling transportation distances between nursery source, cold storage, and planting site vary tremendously across organizations. Long distances require significant planning and labor. This image shows the transportation distance for (a) a private landowner, (b) a government agency, (c) a Tribal organization, and (d) a large real estate investment trust (REIT). (Source: Mast Reforestation 2022)

Table 4. Participating organizations identified various challenges to outplanting success.

Challenges	Percentage of organizations reporting challenge
Planting quality and transportation	78
Terrain and site preparation conditions	67
Nursery supply chain (e.g., seedling availability, quantity, species)	56
Seasonality and climate shifts	56
Labor shortages (e.g., crew members, inspectors)	56

Looking Forward: Addressing Planting Challenges

Improving outplanting capabilities involves addressing multiple pain points (table 4) in the reforestation supply chain. Site visits and interviews revealed how outplanting practices vary across organizations and indicate that future outplanting efforts will require significant investments. These efforts must be allocated towards education on quality planting practices and logistics, addressing difficult terrain and site preparation conditions, expanding nursery seedling capacity, adapting to climate and site environments, and expanding a trained labor force to ensure projects can be completed in the most scalable manner.

Planting Quality and Transportation

Planters and crewmembers must receive appropriate education and guidance to ensure that seedlings are properly handled when in storage, during transportation, and on the landscape to reduce risk of mortality. Based on discussions with planting supervisors, no formal education or training associated with tree planting is provided, mainly due to labor shortages. While formal training would increase the backend costs associated with tree planting, it could inherently increase seedling survival via proper planting and handling techniques and employee retention.

Because crew size varies, and the likelihood of only having one planting supervisor on site is high, supervisors are challenged to ensure that every planter is performing to the industry standard, which often involves the seedling "tug test" method. Inspectors perform this test with a three-finger gentle pulling technique at the top of the seedling (figure 7) to ensure proper seedling placement in the soil (i.e., correct depth, root orientation, and soil compaction) at the desired spacing. Respondents noted that sometimes inspectors were present to provide guidance to planters on their pace and planting quality, but this is the exception rather than the norm. Even with inspection, challenges with J-rooting, L-rooting, compacted roots, deep or shallow roots, and air pockets are recurring issues (Rose and Haase 2006) that require initial and ongoing education. Preliminary education could also involve shadowing an experienced planting team or supervisor during a training period. Additionally, a more direct working relationship among the forester, supervisor, and inspector would help ensure planting requirements are met. While creating and implementing a training regime for planters comes with additional expense, such an effort could greatly reduce expenses associated with planting mortality and replanting requirements, especially given that initial planting costs (e.g., seedlings, labor, and equipment) can range from \$100 to \$200 per acre, with the costs of replanting being even greater (Opalatch and Arney 2019).

Figure 7. Inspectors must ensure quality planting and compliance by (a) establishing plots and (b and c) excavating seedlings to measure stocking density and planting quality. The information from these plots is used to guide planting crews to make adjustments as per forester recommendations. Inspection plots also provide a sample area to project seedling survival. (Photos by Gabriel Altieri)

Planting quality is further influenced by contracts, planting tool(s), and nursery packaging. Achieving stocking densities by incentive structure (e.g., number of seedlings per day) requires significant physical exertion from planters, potentially resulting in substandard planting quality. This exertion may be ameliorated by the planting tool used. The Pottiputki, developed for improved ergonomics and productivity in the early 1970s, is a rare but prime example of coordination across reforestation objectives and nursery production standards. The design of the Pottiputki is intended to reduce physical and cardiovascular strain while maintaining planting productivity, comparable to other planting tools (Appelroth 1971). However, some problems with the Pottiputki make it difficult to use in a variety of ecosystems and terrains. These challenges include planting in hard or rocky soils, inability to plant a variety of stock types, and potentially increased risk of carpal tunnel syndrome and other injuries (Landis et al. 2010, Mullan and White 2002, Oliver and Rickards 2013). Clearly, more work in this realm is recommended, especially given that respondents reported problems with existing tools and equipment. For example, planting bags can fail due to excess weight, shovels are less effective in rockier soils, and hoedads, despite being the more suitable tool for conditions with significant brush, can produce planting holes considered inferior to those achieved using shovels. The quality of the planting, however, will be relative to each planter's planting technique, and the most suitable tool type is based on each planter’s preference (Adams and Patterson 2004). Moreover, planters noted that nursery seedling packaging could be problematic, especially when bags or bindings were too tight, making it difficult to grasp the bags and remove seedlings for planting.

In addition to training and proper planting, infrastructure investments are needed for sufficient and dependable seedling storage at the nursery, during transport, and onsite to maintain seedling quality and ensure the highest potential for survival and growth after outplanting.

Terrain and Site Preparation

Terrain, such as steep slopes, and site conditions, such as heavy brush and other competing vegetation, challenge land managers and planters. Before planting begins, land managers must prepare the site to facilitate the planting by clearing competing vegetation. Although site preparation is always of interest, it is not always achieved due to constricted budgets, low staffing, and short timelines. Multiple land managers in the survey cited an inability to adequately plan a planting operation. One Tribe explained that most of their budget for planting operations is derived from timber harvest revenue, which is prebudgeted to fund their site preparation and planting projects. While this Tribe has historically stayed ahead of the logistical curve, they explained that this revenue stream has been unable to meet the complete cost of site preparation and planting operations, despite their planning. Even when organizations have been able to meet required costs, adverse weather can hamper their ability to complete site preparation before planting. Nonetheless, advanced planning is critical to ensure all requirements are met before seedlings are planted.

In some cases, planters will seek out locations that are more advantageous for seedling growth, known as micrositing. Microsite planting involves positioning a seedling in a spot that provides it with the most favorable environmental conditions for survival (e.g., no vegetation, moist mineral soil, planting hole that is free of duff or debris, and partial shade from stumps, logs, debris, or dead brush) (Castro et al. 2021, Rose and Haase 2006). Based on interviews, reliance on micrositing is increasing as more foresters have experience to back the scientific validity of its efficacy. The micrositing technique may reduce planting efficiency and output, however, as it does not match the incentive scheme for the planters. Based on firsthand accounts with planters, foresters, and contractors in the field, a number of stakeholders explained that microsite-specific contracts significantly reduce the average number of seedlings planted per day per planter. Depending on the terrain and soil composition, a planter will plant an average of 1,200 to 2,000 trees per day. During microsite-specific contracts, however, the expected planting rate can be reduced to 800 to 1,000 trees per day. This shift not only reduces planting efficiency, but also reduces compensation for planters whose contracts are structured on a paid-per-seedling basis. Thus, increasing the adoption of outplanting techniques like micrositing will require a concomitant restructuring of compensation to planters, for instance to meet a per-contract milestone with certain quality assurance metrics.

Nursery Supply Chain

Nurseries have historically been equipped to meet seedling demand, but in recent years, both nurseries and nursery customers have had issues with the timing and seasonality requirements of seedling production. From a nursery customer perspective, one Tribal group informed us that their seedling order was cut in half due to the contracting nursery's inability to complete their requested seedling order in full. This was concerning for the Tribal group, as their grant funding for reforestation had to be used within a certain timeline, and it was unclear if a shift in their planting timeline could accommodate the delay in seedling availability. Similarly, obtaining seedlings has become more challenging across the industry for many stakeholders, with some offering to pay nurseries a premium for seedlings in order to meet their individual demand. One private forest management organization suggested that regardless of the size or resources available to a company, some stakeholders find it difficult to source and acquire proper seedling quantities for projects. These challenges may be attributed to factors such as seedlings being unavailable when planting operations are expected to occur regionally, or larger operations and real estate investment trusts (REITs) utilizing their capital to reserve nursery capacity at the expense of smaller scale customers.

The feedback provided by key stakeholders in the forestry industry demonstrates that many nurseries face infrastructural and logistical challenges in maintaining and expanding their seedling capacity. Expansion efforts are hindered by labor shortages, financial constraints, and market fluctuations as nursery seedling supply changes from year to year depending on project demand (Fargione et al. 2021). To address these issues, nursery education programs need to be implemented and enforced as a method to recruit newfound permanent and temporary nursery employees. Additionally, more research should be dedicated to improving various aspects of seedling production, including restructuring seed grading and processing, modifying growing timelines to accommodate shifting planting timelines, and adjusting fertilization regimes. These and other adjustments can increase efficiency in the seedling production process, therefore allowing nurseries to dedicate more resources towards infrastructure expansion and modernization.

Seasonality and Climate Shifts

Planting timelines are shifting in response to changes in climate. Thus, land managers and foresters must adjust planting windows to avoid adverse environmental effects on seedlings. To better define suitable planting windows, organizations have begun evaluating weather patterns to anticipate planting windows that may yield the highest seedling survival. One Federal organization suggested that ideal planting conditions occur when any sort of precipitation occurs on the landscape (e.g., minor snowfall, snowmelt, rain, etc.) immediately before or after planting. Tried-and-true recommendations will likely still apply, such as avoiding planting when the ground is frozen, during a moderate or greater snowfall event, and/or when seedlings have not been properly cold acclimated.

In the Pacific Northwest, many regions have had drastic increases in temperature perturbation, fluxes from snowfall to strong heat, and extended periods of heat and drought resulting in frequent wildfire events (Halofsky et al. 2020, Keeley and Pausas 2019). To accommodate these shifts, land managers are shifting their planting cycles to the end of the winter and earlier in the spring and incorporating fall plantings. A major challenge of this shift in planting timing begins at the nursery, as most regional forest nurseries sow seedlings to match the conventional growing season and take advantage of ambient growing conditions that reduce energy demands and complexity of operations. Conventional production strategies of regional nurseries have historically been driven by low seedling prices, which constrained nursery owners in their ability to invest in more formidable production systems, more complex logistical operations, and the staff needed to support them. In addition, modifications to nursery and preplanting transportation infrastructure will need to be supported by a flexible and readily available planting workforce with the ability to access remote planting sites in challenging weather conditions.

To ensure smooth transitions as planting windows shift, land managers and nursery managers must work directly and collaboratively to adjust seedling production schedules to enable seedling availability throughout the entire year. Success requires communication between land managers conducting the planting operations, the nurseries providing the seedlings, and the planting teams working on a seasonal status. This will require investments in nursery infrastructure that allow for environmental controls for production of seedlings that may be asynchronous to conventional growing seasons. Additionally, the need for seedlings available at short notice creates a need for improved research into seedling growth, rapid seedling hardening, and short-term cold storage in the context of planting prior to dormancy induction, analogous to "hot-planting" (Landis et al. 2010, Sheridan and Nackley 2022).

Labor Shortages

Surveys and interviews with Pacific Northwest reforestation professionals indicate that a macroscale challenge associated with outplanting is the lack of readily available labor across the forestry industry that is compensated with a heavy reliance on migrant labor pools. This challenge impacts organizations regardless of size and resources. There are simply not enough tree planters that can legally be employed to meet the growing industry demand.

Through the process of meeting with individuals pursuing careers in farming, forestry, or environmental science, including members of Indigenous American communities, migrant laborers, and guest workers from Latin America employed on a seasonal basis through the H-2B visa program, the study found that an increase in labor commensurate with anticipated reforestation demand is necessary. Tribes are less affected by the labor issue because they predominantly, although not exclusively, hire contractors within their community (figure 8). For most private and Federal stakeholders, the labor force is predominantly composed of H-2B visa guest workers, augmented by permanent residents residing in Oregon, Washington, Idaho, or California that have daily commutes of 1 to 4 hours.

Beyond the basic challenges of finding contractors and signing contracts, other issues, such as tardiness or failure to appear at planting assignments, have resulted in project failures. A Federal organization noted that they have experienced issues when trying to hire more planters because the H-2B portal system is poorly designed to address the challenging seasonality of outplanting. Laborers are needed at a certain time, and if that window passes, contractors must look elsewhere for work.

Labor shortage is not solely a Pacific Northwest issue. Currently, there are approximately 11,000 H-2B visa employment opportunities nationally within the forestry industry, most of which are for nursery and planting jobs (Bier 2021). To meet the proposed reforestation goal of planting 25 million acres by 2040 in the Western United States, the combined forestry sectors (private, Tribal, State, and Federal) would need to plant about 400 million seedlings annually (Fargione et al. 2021, Haase et al. 2022). Accomplishing this at a moderate pace (e.g., 1,200 seedlings per day per planter) would require 400 12-person crews (almost 5,000 planters) for approximately 70 total planting

Figure 8. Tribal groups predominantly contract for planting crews within the Tribe. Contractors are often individuals who were previous tree planters with the Tribe. (Photo by Gabriel Altieri, 2022)

days each year. Nationally, planting an estimated 3 billion trees annually (Fargione et al. 2021, Haase et al. 2022) at the same moderate pace would require 3,000 12-person crews (36,000 planters) during optimal planting windows, as seedlings cannot be planted year-round in most of the country. New approaches or dramatic modifications will be needed to accomplish these goals.

One option for meeting these ambitious goals is to reinstate a historic approach similar to that of the CCC where the human element of planting was adequately supported. This support would include wage increases, advocacy from biological experts and silvicultural practitioners, infrastructure support and improvements, educational opportunities, and diversification of the labor pool. Currently in Canada, the tree planter demography tends to revolve around college-age youth who are incentivized to take on seasonal employment opportunities through a mutual, cultural norm, provision of strong infrastructure through Federal facilities, and receipt of competitive wages. This program entices some planters to continue this work as a long-term career. Another approach is to increase and streamline the guest worker process. Collaboration with the agriculture industry and lobbying for an increase in the quantity and quality of H-2B visas is critical, as well as creating more concrete contracting standards to protect front-line workers who have historically been overlooked or exploited. Standards put in place elsewhere can be used as a guideline to meet these reforestation requirements.

Closing Remarks

Currently, existing and emerging technologies, such as growing usage of unmanned aerial vehicles (i.e., drones), helicopters, cable systems, and/or terrestrial solutions have potential to enhance artificial forest regeneration. These technologies can also help drive innovation, improve efficiency, and resolve logistical challenges associated with outplanting seedlings. To utilize these tools in the best possible way, advancements must be made towards revamping how seedlings are supplied, transported, and maintained while on site. Storage facilities and infrastructure must be increased to match nursery capacity. Communication between nurseries, foresters, and contracted crews will be a crucial component in automating these processes.

Indeed, communication must be streamlined to ensure that supply chain challenges, such as shifting planting windows, seedling shortages, and constricted labor pools are overcome. Without clear communication between organizations and contractors, the reforestation pipeline will be clogged. Reforestation requires a subset of complex planning via site maps, silvicultural design, species prescriptions, and materials transport. To ensure that projects are completed without blockages in the pipeline, data and communication between key stakeholders (e.g., land managers, foresters, nurseries, planters, etc.) will be crucial, given the remote challenge of many planting projects.

For the current state of the reforestation pipeline to meet the substantial goals set for the future, researchers must work closely with all parties involved in the reforestation pipeline. Looking backward, evaluating current practices, and looking forward enable assessment of the status of outplanting, pinpoint what has been successful and what has failed, and provide direction for future improvements. Reforestation goals can be met through investment and partnership development to ensure seedling survival at the front and back ends of the reforestation pipeline (Grossnickle and MacDonald 2021).

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