The Finish Line: Post-Planting Activities Improve Reforestation Success

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Abstract

Post-planting activities are not able to remedy major missteps during the reforestation process. They are, however, an important tool to improve seedling vigor and survival in many situations and can have significant long-term impacts on the success and cost effectiveness of reforestation programs. With increasing reforestation challenges for land managers across the West due to invasive weed communities, drought, and other impacts driven by climate change, proactively planned post-planting activities will need to become a standard consideration for reforestation programs. Furthermore, improved reforestation success through the use of post-planting activities will help alleviate seed and nursery capacity constraints for many forest management organizations in the Western United States. 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

Good site preparation and the planting of high-quality seedlings (Wagner 2005) combined with the Target Seedling Concept (Rose et al. 1990) are critical components of a successful reforestation program. The work is not complete, however, when the seedlings are planted. Post-planting activities also play a critical role in ensuring successful seedling establishment and pushing reforestation projects over the conceptual "finish line." Climate change and its associated forest stressors (e.g., drought and extreme temperatures), as well as increasing pressure from pests, diseases, and invasive weed communities, have placed more emphasis on site-specific, "precision-forestry" management approaches that include post-planting activities.

A recent survey of forest landowners (Fargione et al. 2021) indicated that only one-quarter to one-third of forest landowners in the Western United States invest in post-planting activities. The lack of post-planting activities is likely due to a variety of reasons, which are important to explore to better understand the underlying causes and to support the development and implementation of post-planting tools and activities to help meet current and future reforestation goals.

The current large influx of Federal and State reforestation funding provides an opportunity to not only scale up current reforestation pipeline practices but to review and improve those practices and objectives, including post-planting activities. With a constrained nursery capacity in the Pacific Northwest, and insufficient seed for certain species and ecoregions, ensuring that most of the planted seedlings survive and thrive will be an important contribution to minimizing pressure and bottlenecks on the reforestation pipeline.

Post-Planting Challenges

The main challenge to post-planting activities is that most of the variables driving seedling establishment success have already been set. Species, genetic seed source, and stock type have been selected, and the site has been prepared and planted with a certain number of seedlings. After planting, there are no remedies for poor seedling storage, handling, and planting practices, missed microsite planting opportunities, or having the inappropriate species or seed source onsite (figure 1). A high-quality seedling of the appropriate stock type and genetic source is still the foundation to reforestation success. Therefore,

Figure 1. Selecting the wrong species for a reforestation site has long-term negative consequences that can generally not be remedied by post-planting activities. (Photo by Florian Deisenhofer, 2017)

post-planting activities can only address a subset of reforestation challenges and cannot significantly change tree seedling performance if any of the important previous steps were missed or poorly executed.

Unprecedented droughts, megafires, a heat dome, and increasing invasive weeds, insects, and diseases have created significant new challenges for foresters over the last two decades (figure 2). Approaches that have worked in the past are increasingly less likely to result in acceptable outcomes in the future. The ecoregions where managing the water resource for newly established seedlings is paramount will expand significantly in the coming decades. Projects will have to take more site-specific considerations into account, including followup visits to investigate the causes of seedling stress or mortality. Accepting that "trees die" without any followup creates a critical vacuum in the process to continuously improve reforestation success. This viewpoint also impedes a productive relationship with seedling nurseries, which rely on customer feedback to help improve growing practices and target seedling traits.

Another challenge to post-planting activities is an output-oriented mindset to forest management. Organizations have historically focused on cost and process when setting reforestation budgets and measured success based on data, such as number of seedlings planted, acres reforested, acres treated, etc. As seedling, labor, and reforestation costs increase and the seedling capacity is constrained by seed and nursery capacity, it is even more critical to shift to an outcome-based reforestation mindset. Conventional output metrics are not aligned with long-term reforestation success. To improve the current approach, reforestation budgets and goals need to expand to target seedling performance metrics, such as survival, root development, percentage of acres appropriately stocked, time required for seedlings to be free

Figure 2. Nonmerchantable stands on low-productivity sites following wildfire, such as the Cornet-Windy Ridge fire south of Baker City, OR, create challenging decisions for land managers regarding reforestation. (Photo by Florian Deisenhofer, 2017)

to grow (figure 3), cost per surviving seedling, competing vegetation thresholds, and other measures. Such and approach would allow robust assessment of reforestation success and avoid the "plant-and-walk-away" approach.

A lack of useable performance data or capacity to analyze data to support the reforestation decision-making process contributes to the output mindset. As forestry organizations have grown leaner in expertise and resources, less internal capacity exists to summarize and analyze reforestation. Similarly, the capacity to incorporate external research through scientific literature, conferences, and research cooperative projects has been hampered. As data have moved from plot cards and spreadsheets to cloud-based databases and geographic information system dashboards, and remote sensing technologies become increasingly effective for monitoring young plantations, forestry has an incredible opportunity to apply advanced analytics and create meaningful feedback on reforestation performance measures. Those analytics are becoming even more important as the results of reforestation practices vary from year to year in response to increasingly frequent weather extremes. Longer term trend analyses and understanding seedling performance in extreme years will be indispensable for developing critical guidelines on best regeneration practices for a challenging future of reforestation.

Finally, vegetation management as the most important post-planting tool continues to be largely unpopular with the general public. Controversy around the use of herbicides, in particular glyphosate, has heightened public concerns around forest applications and which products are being applied. The forestry community has not been able to send an effective message that planting trees alone may not suffice to achieve adequate seedling survival rates to meet goals of forest restoration, carbon storage, wildlife habitat, water and air quality, and other benefits. Continued engagement with the public and education around forest regeneration activities are needed. The use of "control" plots within operational treatment areas could serve as powerful

Figure 3. To achieve predictable free-to-grow conditions requires selecting the right species, genetics, and stock type, and combining that with an effective vegetation management program including post-planting release. (Photo by Florian Deisenhofer, 2017)

visual examples to highlight the importance of continued post-planting forest management.

Types of Post-Planting Activities

Post-planting activities can be summarized into three broad categories: (1) minimizing physical damage to seedlings from animals, (2) minimizing seedling stress due to low water availability, and (3) monitoring seedling performance. Activities for each of these are summarized in the following sections.

Minimizing Physical Damage to Seedlings From Animals

Ungulate browse damage impacts seedling establishment and growth across many regions. Managing logging slash before planting along with microsite planting can significantly reduce post-planting ungulate browsing (figure 4). When slash is piled, it creates favorable planting microsites along the edges, and when it is left scattered, it impedes animal movement. Although tedious, moving slash after planting can protect susceptible seedlings. Slash plays only a small part, however, in the multipronged approach often needed to address browsing damage. Therefore, post-planting tools for browse prevention and reduction, such as repellents, bud caps, netting, tubes, and fencing, are useful depending on the site location, value of the planted seedlings (e.g., grafted orchard seedlings, or seedlings in research plots), and browsing severity (figure 5). An organization's objectives and budget priorities as well as the assumptions regarding the efficacy of the various treatments will determine what, if any, post-planting browse protection should be applied. One promising new alternative is a recently approved repellent

Figure 4. Microsite planting along an old down log, combined with manual slash placement (branch in front of the seedling) can minimize browse damage, which is particularly important for the first growing season. (Photo by Florian Deisenhofer, 2022)

Figure 5. Mesh tubes are commonly used to protect high-value or browse-susceptible seedlings from animal damage. (Photo by Florian Deisenhofer, 2022)

product on the U.S. market, Trico® Pro (Kwizda Agro GmbH, Vienna, Austria). This product has been shown to prevent browse damage for 6 months in early trials on western redcedar (*Thuja plicata* Donn ex D. Don) in western Washington (WADNR data, unpublished).

Cost and efficacy among the various treatment options vary substantially and need to be evaluated on a site-specific basis in conjunction with the management objectives. The best choice depends on factors such as species, length of protection desired, anticipated mortality, time delay for seedlings to be free to grow, stocking objectives, labor availability, assumed risk, local experience with browse severity, etc. As mentioned previously, the output-oriented mindset and the lack of data and analysis combined with a focus on short-term costs can get in the way of selecting the best option. A performance-based analysis to see which treatment option(s) result in seedlings that are free to grow in the shortest time and at the lowest long-term cost would be best. For western redcedar in particular, the cost of no post-planting protection can often be the most expensive pathway per free-to-grow seedling (figure 6).

A new study associated with the T3 Watershed Experiment (https://www.onrc.washington.edu/t3-watershed-experiment/), a collaborative research project between the University of Washington and the Washington Department of Natural Resources on the Olympic Peninsula in Washington, will compare various browse protection approaches for western redcedar and provide data to better support decision makers.

Minimizing Seedling Stress Due to Low Water Availability

With increasing frequency and duration of droughts, managing water availability to seedlings is the single most important step to ensure post-planting seedling survival. For high-value plantings such as seed orchards, irrigation is a common practice to ensure survival and establishment during the first few growing seasons. The Oregon Department of Forestry J.E.

Figure 6. Western redcedar seedlings planted in alternating rows with Douglas-fir on a site in the foothills of the southwestern Washington Cascades have still not reached free-to-grow condition after 12 growing seasons. (Photo by Florian Deisenhofer, 2022)

Schroeder Seed Orchard (St. Paul, OR) increased grafted seedling survival by more than 40 percent by proactively irrigating new orchards during the first two growing seasons (Kaczmarek 2022). With regard to traditional reforestation sites and climate change, regions that have been historically successful in ensuring adequate soil moisture with minimal vegetation management may need to increase active management of competing vegetation to minimize water stress. Additionally, retaining logging slash can contribute to soil water retention by minimizing the establishment of competing plant species (Harrington et al. 2013) and reducing heat and evaporation at the soil surface. Whole-tree harvesting methods, often combined with slash piling, have generally reduced slash loading across reforestation sites and thus reduced the potential for slash to significantly contribute to soil water availability for seedlings. For those sites, therefore, the most practical and financially feasible tool is to control competing vegetation, which minimizes soil water loss and increases light and nutrient availability.

Extensive research shows that controlling competing vegetation can tremendously increase forest productivity across North America (Wagner et al. 2006). Gonzalez-Benecke and Dinger (2018) concluded that preserving soil moisture until early August through vegetation management was critical for maximizing stand productivity for Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) in the Pacific Northwest. The greatest gains in forest productivity through water management are generally achieved in areas with challenging climatic conditions for survival, such as southwestern Oregon and on the east slopes of the Cascades in Oregon and Washington. In eastern Oregon, seedling survival increased significantly when vegetative competition was controlled through herbicides or weed mats; using tree shade cards (Terra Tech, Eugene, OR) also significantly improved survival, especially for seedlings that did not receive an herbicide treatment (Oester 2008).

The need for vegetation management and the magnitude of responses to treatments depends on climatic, topographic, and soil variables of the reforestation site, such as annual and growing season temperature and precipitation patterns, soil water-holding capacity, aspect, slope, and elevation. Wildfires often occur on low-productivity sites with poor water-holding capacity and low growing season precipitation, making them difficult places in which to quickly reestablish forests without vegetation control. Tree species and stock type, as well as the type and biomass of competing vegetation, are also influencing factors. Grasses and herbaceous vegetation have a significant effect on early seedling survival and growth (figure 7). The greatest threat to long-term survival and forest productivity is unwanted hardwoods and shrubs (Wagner 2005). Many competing woody plants can be effectively controlled with mechanical treatments (Balandier et al. 2006). Herbicides can be used to control all types of vegetation and are particularly efficient for controlling grasses and herbaceous vegetation.

Shallow-rooted tree species such as western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) and western redcedar may need more vegetation management than deeper rooted, early seral species such as coast Douglas-fir or ponderosa pine (*Pinus ponderosa* Lawson & C. Lawson). The Vegetation Management Research Cooperative at Oregon State University (VMRC) showed a correlation between initial aboveground

Figure 7. Ponderosa pine seedlings planted in the Carlton Fire Complex (2015) with post-planting vegetation control were two to three times more likely to survive than seedlings planted without vegetation control. (Photo by Florian Deisenhofer, 2022)

seedling size and vegetation management needs; seedlings with greater shoot volume needed more vegetation management, likely due to larger transpirational water loss (Wightman et al. 2019). When working with herbicides to control vegetation, particularly after seedlings have been planted, herbicide selection is critical to ensure no damage to seedling vigor aboveground or belowground. Seedling vigor post-treatment should be the primary response variable to determine treatment performance, not just vegetation cover. Damage to the roots by soil-active herbicides often goes unnoticed but can be particularly harmful, especially on tough or droughty reforestation sites (figure 8). Root damage can offset any benefits of improved soil water availability through vegetation management. Climate conditions play a critical role in herbicide breakdown. Thus, foresters in regions with cold and dry climates need to be particularly careful with timing and rates of soil-active herbicides.

Performance Monitoring

Significant advances have been made through the collection of seedling and plantation performance data and subsequent analysis. With today's advances in digital data collection and visual display in geographic information systems, processing and viewing large datasets across space and time—and making them easily available to anyone—are easier than ever. Obtaining reliable post-planting seedling performance data such as survival, growth, and damage, as well as competing vegetation data, can greatly increase the understanding of which factors are most responsible for driving reforestation success (or failure) and help prioritize any followup treatments, if needed. Common variables that can be analyzed for their correlation with seedling performance are nursery, stock type, species, planting season, planting contractor, planting quality, seedling storage length, seedling storage type, and herbicide rates. These annually collected datasets will not only highlight issues in a particular year but will also provide information on trends over time. Performance data build the foundation of a large-scale understanding of what works, what does not work, and where more research or different approaches are needed. Such data and analyses may show that practices that have been previously deemed unaffordable are actually critical to success.

Figure 8. Assessing the development of new root tips during the first season of planting is often the only way to identify damage from commonly used soil-active herbicides such as sulfometuron, metsulfuron, imazapyr, etc. Aboveground seedling appearance may not display any damage as seen in this 1-year-old ponderosa pine seedling excavated in late August of the first growing season. (Photo by Florian Deisenhofer, 2022)

The most important post-planting monitoring tool is a shovel. Ultimately, seedlings can only perform well when they grow roots. Thus, belowground examination of seedlings provides the most important assessment of field performance (figure 9). Establishment of common gardens is particularly helpful (without applying root-damaging herbicides) to provide a level playing field for all species, stock types, and nursery sources (figure 10). Digging trees during the spring and fall root-growth periods can be instrumental in under-

Figure 9. Belowground assessment of seedlings after outplanting is essential for assessing planting success. Ideally, seedlings will exhibit vigorous root growth such as (a) this container seedling planted in May and excavated in August 2022 near Colville, WA. Seedlings that appear healthy aboveground may have no new visible roots such as (b) this seedling when excavated in early October after one growing season near Nanaimo, BC. (Photos by Florian Deisenhofer, (a) 2022 and (b) 2019)

Figure 10. Common gardens are extremely useful test plots to identify seedling quality issues, assess root development, and test post-planting tools such as physical seedling protectors. (Photo by Brian Williams, Washington Department of Natural Resources, 2022)

standing tree seedling performance after planting. Seedlings can often appear healthy aboveground during the first growing season by living off stored carbohydrates from their life at the nursery. Only looking at roots can provide a true glimpse of seedlings' future performance potential and help trace problems back to their figurative "roots." Common gardens are also great communication tools between field foresters and nursery growers to facilitate feedback on operational performance of specific crops and to compare their success with others.

Benefits of Post-Planting Activities

There are several reasons to carry out post-planting activities. As described in the following sections, improved survival and growth are the primary objectives.

Survival

Post-planting activities to prevent expected regeneration failures are of foremost importance. Without survival, all investments into the seed, nursery, and outplanting components of the reforestation pipeline are lost. After planting, management goals are to overcome planting stress and establish the seedling on the planting site by root-soil contact as fast as possible (Grossnickle 2012). During the first few post-planting growing seasons, providing an environment safe from animal damage and with enough soil moisture in the seedling rooting zone is critical for survival.

Forest managers across the Pacific Northwest and Intermountain region have observed the rapid expansion of invasive weed species communities over the last two decades, such as woodland ragwort (*Senecio sylvaticus* L.), prickly lettuce (*Lactuca serriola* L.) and Canadian horseweed (*Conyza canadensis* L.) (figure 11). Those species have several traits in common, such as rapid growth and flowering, long germination periods during the spring and fall, large amounts of small, wind-dispersed seeds, and resis-

Figure 11. A thick cover of woodland ragwort often emerges in Pacific Northwest plantations during the first growing season following summer site preparation with herbicides and no post-planting release. (Photo by Florian Deisenhofer, 2022)

tance to commonly used soil-active forestry herbicides. Many landowners have documented an increase in forb cover following site preparation with herbicides during the first few growing seasons compared with control treatments. Since invasive forb species are adapted to aggressively exploit soil water resources in the same soil depth as newly planted seedlings (Cowden et al. 2022), they can be as, or more, competitive than untreated natural vegetation (Balandier et al. 2006). The competitive nature of invasive forb communities can be underestimated and lead to substantial seedling mortality, especially in drought years and on harsh sites.

In ecoregions with prolonged droughts, risk assessments to integrate seedling vigor, competing vegetation levels, site factors, and weather predictions are difficult, if not impossible (Schneider et al. 1998). Therefore, routine post-planting activities such as release from competing vegetation or shade card placement should be considered an "insurance policy" against above-average seedling mortality. In years with mild growing conditions, those treatments still provide a benefit to seedling vigor and growth, even when survival is largely unchanged, and they can mitigate undesirable seedling morphological characteristics such as high shoot-to-root ratios or poor root structures that may negatively impact seedling survival (Wightman et al. 2019). Regularly scheduled post-planting treatments generate more predictable outcomes of seedling survival with many long-term benefits. Closely monitoring hundreds or thousands of acres and rapidly responding to post-planting problems each year are challenging, whether due to constrained budgets, tight timelines, or limited personnel and labor resources. Proactive, preventative post-planting care decreases the overall establishment costs by minimizing replant and inter-plant acres to achieve desired stocking levels, decreasing the time needed to get stands free to grow, and reducing administrative workloads. On a broader scale, post-planting care saves valuable seed and nursery growing space for each organization, while freeing up capacity for the forest nursery sector.

Post-planting activities can also effectively reduce seedling mortality when unexpected challenges arise such as animal damage, frost damage, or lethal levels of competing vegetation. Those unplanned treatments are typically not as effective in maintaining seedling vigor as preventative methods because they commonly occur past the prime window of efficacy. Nonetheless, such treatments are still worth pursuing as they may still be able to salvage acceptable survival results and avoid the negative impacts described previously.

Growth

Post-planting activities can also enhance seedling growth, particularly stem diameter and volume growth, as stem diameter is more sensitive to competitive stress than height growth (Dinger 2018, Dinger and Rose 2009, Wagner 2005). Implementing post-planting activities can reduce the amount of time needed to meet management objectives, such as "green-up" requirements from State regulations, habitat thresholds, or carbon capture targets. This gain in seedling growth rates can be expressed as "age shift"—the number of years that trees with treatments are ahead compared with a control treatment. The VMRC analyzed data from 2 sites in Oregon after 20 growing seasons and showed that post-planting treatments generated age shifts between 0 and 10 years, depending on species and site (Gonzalez-Benecke 2021). Although some treatments were not operational, that research shows the incredible impact that post-planting treatments can have. In general, shade-tolerant species responded more to post-planting vegetation-management treatments than Douglas-fir, likely due to their being more shallow-rooted species and therefore more susceptible to drought stress.

Animal damage protection can also result in many years of age shift. A Washington Department of Natural Resources case study (unpublished) in southwest Washington showed a height difference of more than 700 percent after six growing seasons between western redcedar seedlings planted inside a fence compared with seedlings planted outside the fence (figure 12). Height growth of seedlings outside the fence was negligible for 6 years following the first growing season due to animal damage.

Studies looking at the timing of post-planting treatments generally show better survival and growth responses when treatments are applied in the first growing season (Gonzalez-Benecke 2021). This time is when seedlings are most susceptible to environmental stress as they are getting established on the planting site. Once seedling vigor is compromised, such as through foli-

Figure 12. Fifteen-year-old western redcedar seedlings planted inside a fence (background) have experienced many years of "age shift" compared to seedlings planted outside the fence (foreground with forester and western hemlock naturals) on a site near Longview, WA. (Photo by Florian Deisenhofer, 2021)

age loss by ungulate browsing or water stress through competition, it takes time for seedlings to recover and resume normal growth. Delayed treatments beyond the first growing season, however, can still have significant benefits, especially when applied during challenging years.

Conclusion

Post-planting activities play a critical role in pushing seedlings over the "finish line" to survive and perform in the long term. These activities cannot address certain mistakes that may have occurred during the nursery or outplanting phase of the reforestation pipeline. The correct species, genetics, stock type, and especially the quality of the seedling combined with correct storage and handling practices are still central to a successful outcome. Post-planting activities do, however, have the capacity to significantly reduce the strain on the reforestation pipeline by minimizing seedling mortality and therefore saving much-needed seed and nursery space along with optimizing precious reforestation staff time and resources. Post-planting activities can greatly accelerate stand development, creating significant age shifts by pushing seedlings to a size and vigor whereby they are much less vulnerable to animal damage or induced stress from water competition. Most importantly, post-planting monitoring is a superior method to acquire the necessary data to drive continuous improvement and innovation in operational reforestation and help landowners adapt to new challenges brought on by climate change.

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