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Tamm Review: Reforestation for resilience in dry western U.S. forests

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ABSTRACT

The increasing frequency and severity of fire and drought events have negatively impacted the capacity and success of reforestation efforts in many dry, western U.S. forests. Challenges to reforestation include the cost and safety concerns of replanting large areas of standing dead trees, and high seedling and sapling mortality rates due to water stress, competing vegetation, and repeat fires that burn young plantations. Standard reforestation practices have emphasized establishing dense conifer cover with gridded planting, sometimes called 'pines in lines', followed by shrub control and pre-commercial thinning. Resources for such intensive management are increasingly limited, reducing the capacity for young plantations to develop early resilience to fire and drought. This paper summarizes recent research on the conditions under which current standard reforestation practices in the western U.S. may need adjustment, and suggests how these practices might be modified to improve their success. In particular we examine where and when plantations with regular tree spacing elevate the risk of future mortality, and how planting density, spatial arrangement, and species composition might be modified to increase seedling and sapling survival through recurring drought and fire events. Within large areas of contiguous mortality, we suggest a "three zone" approach to reforestation following a major disturbance that includes; (a) working with natural recruitment within a peripheral zone near live tree seed sources; (b) in a second zone, beyond effective seed dispersal range but in accessible areas, planting a combination of clustered and regularly spaced seedlings that varies with microsite water availability and potential fire behavior; and (c) a final zone defined by remote, steep terrain that in practice limits reforestation efforts to the establishment of founder stands. We also emphasize the early use of prescribed fire to build resilience in developing stands subject to increasingly common wildfires and drought events. Finally, we highlight limits to our current understanding of how young stands may respond and develop under these proposed planting and silvicultural practices, and identify areas where new research could help refine them.

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1. Introduction

Recent increases in wildfire and drought-related mortality have created significant reforestation challenges for managers. For example, in California the annual area burned since 2000 (228,000 ha) is double the annual area burned over the previous three decades (FRAP, 2018). Equally problematic for managers, the increase in area burned has been accompanied by a dramatic increase in the proportion of burns experiencing crown fire (e.g. in yellow pine/mixed conifer forests the high severity fraction has increased from an historical range of 4–13% to 32% (Miller and Safford, 2012; Safford and Stevens, 2017; FRAP, 2018)). Large, stand-replacing fires lead to sizeable areas without nearby seed sources for non-serotinous tree species and thus natural regeneration is frequently inadequate, especially > 200 m from a live tree seed source (Greene and Johnson, 1996; Welch et al., 2016; Stevens et al., 2017). In addition, droughts such as California's 2012–2016 event that killed an estimated 129 million trees in the Sierra Nevada, can result in watersheds where near-complete overstory tree mortality may limit natural regeneration.

It is not just the extent of tree loss, however, that is challenging management capacity. If the frequency and severity of wildfire (Keyser and Westerling, 2017) and drought (Adams et al., 2009; Allen et al., 2010; Williams et al., 2013; Griffin and Anchukaitis, 2014) events increase, as most climate change models suggest (Restaino and Safford, 2018), then regeneration practices must also promote increased drought and fire resilience in young stands. For example, California's 2013 Rim Fire re-burned many areas that had been planted at 300 + trees per acre (tpa; 740 + trees per hectare [tph]) after the 1987 Stanislaus complex wildfire. Most of these young plantations supported rapid fire spread and high fire intensity, resulting in 100% mortality (Lydersen et al., 2014, 2017). Even in areas that escape re-burning for decades, mortality has increased with the frequency and severity of western U.S. drought, with the rate of mortality correlated with stand density (Young et al., 2017; Stevens-Rumann et al., 2018).

Many of the standard reforestation practices arose from controlled field trials focused on testing different regular spacing densities and subsequent silvicultural treatments such as thinning, fertilization, and control of competing vegetation. On public lands, a shrinking work force and tighter budgets often reduce or eliminate second-entry practices, a trend that is expected to continue (Landram, 1996). This means initial arrangement and density need to be carefully considered, as opportunities for 'course correction' with silvicultural tools are becoming more limited. Regular spacing at high density fails to produce both the spatial pattern that recent research has suggested is associated with greater fire and drought resilience, and the diversified structure that is optimal for wildlife habitat and species diversity (Larson and Churchill, 2012).

Many of the ideas we propose have been tried informally in various combinations and contexts by silviculturists, but few examples are available in the literature to provide guidance and spur improvements. Experience has accordingly remained site-specific so that we lack general guidelines. Nonetheless, recent work increasingly supports a critical role for variable forest structure from the scale of individual trees up to the forest landscape (North et al., 2009b, Hessburg et al., 2015, 2016). There is also a focus on modifying silvicultural practices to incorporate ecosystem function into improving forest restoration (Stanturf et al., 2014). We believe these principles suggest concrete ways to harness ecological processes to pull young stands in the direction of higher resilience as well as providing habitat for a broader array of species. In this paper we focus on yellow pine (*Pinus ponderosa* and *P. jeffreyi*) and mixed-conifer forests on federal lands in California's Sierra Nevada. However, the changes in reforestation practices we propose are appropriate for dry western forests of any ownership that historically had a frequent, low-moderate severity fire regime.

In this paper we first identify the conditions under which standard reforestation practices may result in high mortality, and then examine how planting practices, particularly with regard to spacing and density, could be modified to increase seedling survival and build early drought and fire resilience. Finally, we address likely criticisms of this approach and summarize where new research could help optimize planting strategies.

2. Reforestation challenges

2.1. Current reforestation practices

Reforestation on U.S. Forest Service lands is guided by the National Forest Management Act, which directs that forest lands that have been "cut-over or otherwise denuded or deforested" be reforested, and that harvested areas must be reforested within 5 years of harvest (NFMA, 1976 [Section 6 E ii]). Areas are planted when silviculturists determine that natural processes will not achieve the preferred stocking, species composition, growth rates or forest structure within a desired time-frame. Timing is an important variable as costs and control of competing vegetation generally increase with time since disturbance (McDonald and Fiddler, 1993; Smith et al., 1997).

Steps in the reforestation process may include salvage logging (removal of standing dead timber, both for sale to fund subsequent reforestation steps, and for worker safety), site preparation (which includes segregation or removal of slash and exposure of mineral soil for ease of planting), planting of seedling stock (generally conifers), competition control for enhancing both seedling survival and growth, and, later, pre-commercial or commercial thinning. The specific treatments often vary depending on aridity, forest type, understory vegetation, and social acceptance of specific practices (i.e. tilling for site prep, use of herbicides, etc. (Schubert and Adams, 1971, Helms and Tappeiner, 1996)).

Historically, planting programs in western U.S. forests were focused on reforesting harvested areas, old burns, and non-stocked areas considered capable of supporting forest. Early reforestation efforts were plagued with low survival due to a variety of factors including poor stock, and thus high densities (435–680 tpa; 1075–1483 tph) were considered necessary (Schubert and Adams, 1971). Despite improvements in nursery practices (planting stock and seedling handling) and onsite practices (site preparation and management of competing vegetation), reforestation has continued to focus on establishing regularly-spaced trees (125–300 tpa [309–741 tph]) depending on site class and forest type) (Fig. 1). This planting strategy is designed for full site occupancy (i.e. a closed canopy forest) and the capacity to produce an intermediate commercial harvest (USDA Forest Service, 1989).

Once trees are established, follow-up treatments are often required to promote the growth and survival of planted trees (i.e. "release") in the first five years. In areas where planted trees are more widely spaced, drought stress can be exacerbated by the rapid growth of shrubs and grasses in the high-light environment between trees and increase competition for nutrients and soil moisture, (Lanini and Radosevich, 1986; Riegel et al., 1992; McDonald and Fiddler, 2010; Bohlman et al., 2016). Competing vegetation is reduced manually, mechanically, or with herbicides.

By contrast, trees initially planted at high densities may experience less competition from shrubs and grasses as crowns interlock early and reduce light to the understory (Rubilar et al., 2018). As trees mature, however, intertree competition reduces growth rates and increases the probability of density-dependent mortality. Thus additional follow-up treatments are often required, such as pre-commercial thinning and mastication (Stephens and York, 2017) to reduce intertree competition and to adjust species composition and tree spatial patterns (Long, 1985).

This intensive approach to reforestation can be cost prohibitive. Despite the need for follow-up treatments, over the past 20 years there has been a substantial decline in the number of hectares treated on National Forest lands. On these lands in the western U.S. (Regions 1-6),