RESTORING PONDEROSA PINE IN THE DAVIS MOUNTAINS OF WEST TEXAS: IMPACTS OF PLANTING PRACTICES ON SEEDLING SURVIVAL

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Abstract—The ponderosa pine forests (*Pinus ponderosa* Laws.) in the Davis Mountains of west Texas recently experienced a major mortality event that resulted, in part, from profound regional drought predisposing trees and stands to mortality from both western pine beetle (*Dendroctonus brevicomis*) and wildfires. To evaluate alternatives for restoration and recovery, the Texas A&M Forest Service (TFS) initiated "Operation Ponderosa" in cooperation with The Nature Conservancy (TNC), on the TNC Davis Mountains Preserve in Jeff Davis County, TX. The loss of overstory pines and lack of natural regeneration pose a considerable challenge to management. A pilot study was commisioned to investigate artificial regeneration of ponderosa pine using containerized seedlings and site preparation alternatives. Early survival was poor, mainly due to below-ground herbivory, which was identified as the principal short-term obstacle to artificial regeneration in the Davis Mountains. The larger question of ponderosa pine recovery, particularly if local climatic conditions become increasingly unfavorable, remains.

INTRODUCTION

Ponderosa pine (*Pinus ponderosa* Laws.) is one of the most important conifers in the United States. With native populations in every state that lies west of the 100°W meridian (except Kansas), it is one of the most widely distributed pines on the continent (Oliver and Ryker 1990). The largest ponderosa pine population in Texas occurs in the Davis Mountains, much of it owned or protected by The Nature Conservancy's (TNC) Davis Mountains Preserve.

Across much of the range of ponderosa pine, and particularly in the Southwest, "megadisturbances" or major mortality events have weakened or decimated many stands (Millar and Stephenson 2015, Reynolds and others 2013). These events are usually the confluence of economic, environmental, ecological, and policy influences that both individually and collectively have acted as stressors to forest health and vigor over the past century. In the Davis Mountains, for example, forests underwent a densification process that started around the turn of the 20th century (Bataineh 2006, Poulos and others 2013). This process increased piñon-juniper density from approximately 100 trees per acre in 1890 to over 1,100 trees per acre in 2005 (Bataineh 2006). Livestock grazing was likely the only mechanism reducing density through much of the 20th century. A concomitant change in the historic fire regime also occurred. Fire-return intervals averaged about 5 years before 1937, but fire-free periods increased to 20–40 years thereafter (Poulos and others 2013). Because of the difficult terrain and the sparse distribution of the species across the area, local timber markets are absent, and no sawmill is reported within 300 miles (Prestemon and others 2005).

In the 1990s, these dense forests experienced an extended period of elevated temperatures and profound drought coupled with secondary bark beetle attacks. In 2011–2012, wildfires burned through several stands across the Davis Mountains. This major mortality event (fig. 1) resulted in a reduction of ponderosa pine from an estimate of over 800 trees per acre on parts of the TNC Davis Mountains Preserve in 2004 (Bataineh 2004) to an estimated 17 trees per acre across the Preserve in 2014 [Texas A&M Forest Service (TFS), unpublished data], with bark beetle attacks ongoing. There was a near complete lack of ponderosa pine seedlings observed and a paucity of cones on surviving mature trees 4 years after the wildfires (TFS, unpublished data).

To evaluate alternatives for restoration and recovery of the TNC Davis Mountains Preserve, TFS initiated "Operation Ponderosa," in cooperation with TNC and other partners. One of the primary goals of Operation Ponderosa was to foster ponderosa pine regeneration,

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Figure 1—Tree mortality has been catastrophic and widespread across the Davis Mountains Preserve as a result of drought, insect attack, and wildfire. Though all species have been affected by this major mortality event, it has been most notable for ponderosa pine, and many fully-stocked stands have been decimated. (photo by Lance A. Vickers)

by both natural and artificial means. Because science-based silvicultural guidelines are not available for ponderosa pine in the Davis Mountains, several questions regarding the best practices for artificial regeneration exist. These questions include identification of appropriate planting season and early cultural treatments that promote survival and growth. To begin addressing these questions, a planting demonstration study on artificial regeneration of ponderosa pine in the Davis Mountains was commissioned. This demonstration used locally sourced containerized seedlings raised by TFS and a set of low-cost, easily applied site preparation alternatives feasible for the remote, rugged terrain.

METHODS

Site Description

The Davis Mountains of west Texas (≈ -104.1, 30.7) are approximately 35 million years old, predominantly igneous in origin, and range in elevation from about 5,000–8,000 feet. Baldy Peak atop Mt. Livermore is the highest point at 8,382 feet in elevation. The Köppen climate type is cold semi-arid, with average minimum temperatures (at 6,790 feet elevation) ranging from 32 to 59 °F (January to July) and average maximum temperatures ranging from 54 °F in January to 85 °F in June. Annual precipitation includes about 19 inches of rainfall and 5 inches of snowfall on average with the majority occurring in a distinct monsoon pattern from June–September.

Vegetation communities in the Davis Mountains are transitional and range from Chihuahuan grasslands to sky island relict forests with increasing elevation (Hinckley 1944). At midelevations piñon woodlands and oak-piñon-juniper woodlands dominate, whereas at higher elevations ponderosa pine is more prevalent and mixed conifer-hardwood assemblages dominate (see Bataineh and others 2007, Poulos and Camp 2010, and Poulos and others 2007 for more detail).

Planting Demonstration Description

Three stands formerly dominated by ponderosa pine within the TNC Davis Mountains Preserve were used for the Operation Ponderosa planting demonstration. These stands all experienced some degree of ponderosa pine mortality during the wildfires in 2011–2012, and subsequently received a thinning treatment in 2015 that aimed to reduce the density of surviving ponderosa pine competitors not strongly affected by the wildfires (primarily *Juniperus* and *Quercus* spp.). The residual basal area in these three stands averaged 15.3 square feet per acre with ponderosa pine as the chief contributor, making up about 65 percent of the basal area. Other common species were gray oak (*Q. grisea* Lieb.), Emory oak (*Q. emoryi* Leib.), alligator juniper (*J. deppeana* Steud.), and piñon pine (*P. cembroides* Zucc.). Several other comparatively rare oaks were present along with black cherry (*Prunus serotina* var. *virens* McVaugh) and Texas madrone (*Arbutus xalapensis* Kunth).

Soils in these stands were predominantly composed of the Loghouse association (Loamy-skeletal, mixed, superactive, mesic Typic Haplustalfs); soils were uniform within each stand (http://websoilsurvey.nrcs.usda.gov/). The Loghouse association typically is a deep and well-drained loam with low available water storage in the profile.

The Operation Ponderosa planting demonstration was a replicated comparison of three weed control treatments and two planting seasons (dormant and monsoon). The dormant season planting (November 2015) included five weed control comparison replicates in each of the three stands in the study. Insufficient stand access and poor nursery survival precluded a full installation (comparable to fall 2015) of the monsoon season planting treatment (August 2016) in all three stands used for the dormant season planting. As a result, only four full replicates were established in two of the stands for the monsoon season planting. Given the within-stand soil uniformity, there was no need for within-stand statistical blocking, and the planting group locations were randomly located within each stand.

For the dormant season planting, 450 containerized (1-0, D40) seedlings developed from local seed sources were used. In the monsoon season planting, the 257 containerized (2-0, D60) seedlings used were of the same cohort as the dormant season seedlings but stepped up from D40 to D60 containers and held longer in the nursery (approximately 1 additional year). The D40 dormant season seedlings had an average root collar diameter of 0.16 inch and stem height of 5.43 inches with an approximate average root:shoot ratio of 2:1. The D40 seedlings were planted to a "first-green" depth, i.e., to the base of live foliage. The larger D60 monsoon season seedlings had an average root collar diameter of 0.23 inch and stem height of 7.12 inches, with an approximate average root:shoot ratio of 2:1, although there was considerable variation in height, diameter, and overall condition of these older seedlings. Due to rocky soil at depth, the D60 seedlings were planted only to container depth, i.e., no more of the stem was buried at planting than was in the containers.

Planting Details

Dormant season planting occurred on November 17–18, 2015. The local weather was clear and cool (27–63 °F) with relative humidity ranging from 34–41 percent and 14 to 19-mile-per-hour westerly winds reported nearby. There was slight rainfall (approx. 0.1 inch) reported in the area before planting and 2.95 inches reported during the week following planting. Monsoon season planting occurred on August 30–31, 2016. The local weather was overcast and mild (36–70 °F) with high relative humidity (87 percent) and 3 to 4-mile-per-hour northeasterly winds reported. There was approximately 1 inch of rainfall reported in the area during the 2 weeks before planting, about 1 inch during planting, and another 1 inch over 2 weeks following planting.

Localized group structures within uneven-aged stands are commonly observed in frequent-fire forests of the Southwest (Reynolds and others 2013). Field observations in the Davis Mountains Preserve found a consistent pattern of several saplings and small pole-sized trees in groups of approximately four to ten trees behaving more or less as a congeneric group with spacing varying from about 5–20 feet (fig. 2). A triangular

Figure 2—Large saplings and small pole-sized ponderosa pine commonly occurred in a grouped pattern on the Preserve. Field observations found a consistent pattern of groups of approximately four to ten trees behaving more or less as a congeneric group with spacing varying from about 5–20 feet. Localized group structures within uneven-aged stands are commonly observed in frequent-fire forests of the Southwest (Reynolds and others 2013). (photo by Lance A. Vickers)

planting pattern (i.e., ‘Guldin Triangle’) with groups of 10 ponderosa pine seedlings all within a 0.02-acre circular plot and having an 8-foot spacing among neighbors was devised and employed to mimic the observed structure for the planting demonstration (fig. 3). Planting group locations within each stand were randomly determined but constrained to avoid roads, streams, large residual trees, or severe planting constraints (e.g., large slash piles, excessive boulder/rock cover).

Weed Control Treatments

Site preparation treatments for the planting demonstration were a No Weed Control (NWC) treatment as an experimental control and two herbaceous weed control treatments that could be readily applied by a hand crew. The two herbaceous weed control treatments included were Chemical Weed Control (CWC) and Physical Weed Control (PWC).

The CWC treatment consisted of a backpack application of Oust® XP (sulfometuron methyl, Bayer CropScience LP) at a rate of 2 ounces per acre (the lowest labeled rate for herbaceous weed control) in 20 gallons of water per acre. The herbicide was applied to the entire 0.02-acre circular planting group area. For convenience, a single application on April 20, 2016 was used for both the dormant season and monsoon season plantings. For the dormant season planting, this timing was consistent with labeled recommendations for post-planting release applications. Nonetheless, the dormant

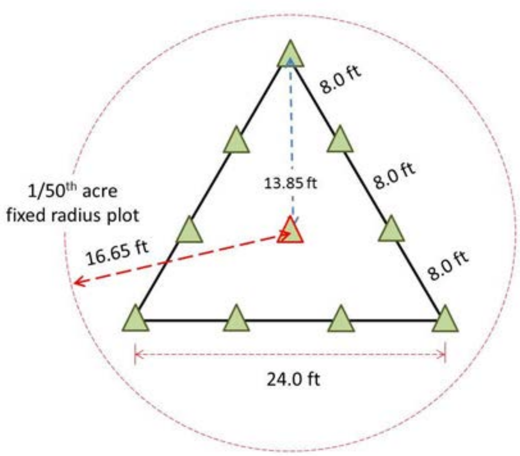

Figure 3—The ‘Guldin Triangle’ planting unit was a 10-seedling triangular group devised to mimic observations of grouped ponderosa pine regeneration on the Davis Mountains Preserve. Field observations found a consistent pattern of several saplings and small pole-sized trees in groups of approximately four to ten trees behaving more or less as a congeneric group with spacing varying from about 5- to 20 feet. The equilateral triangle planting group is 24 feet on each side, with 10 seedlings each spaced 8 feet apart within the triangle. This design fits within a 0.02-acre fixed radius plot (16.65-foot radius) and was easy to install in the field.

season seedlings were covered during application as a precaution. For the monsoon season planting, the April timing was, in essence, a site-preparation application. On followup visits, the impact of the herbicide application on competing herbaceous vegetation was evident though somewhat inconsistent, and complete control of competing vegetation was not achieved for any planting group.

The PWC treatment consisted of a 4-square-foot fibrous mat installed around each seedling at the time of planting. The mats were installed over any existing herbaceous vegetation (some clearing was required when excessive) and secured to the ground using landscape staples. A small incision was made in the center of the mat to accommodate the planted seedling and subsequently closed using landscape staples.

Data collection

Immediately following outplanting, ground line diameter and stem height were measured on all planted seedlings. Survival surveys on the dormant season plantings were conducted approximately 1 month (December 2015), 3 months (February 2016), 5 months (April 2016), 6 months (May 2016), 7 months (June 2016), 9 months (August 2016), and 13 months (December 2016) following planting. Survival surveys on the monsoon season plantings were conducted approximately 4 months (December 2016) following planting.

Statistical Analysis

Mixed effects logistic regression via the glmer function in the lme4 package (Bates and others 2015) for R (version 3.3.2, R Core Team 2016) was used to compare survival among the various treatments. Because the planting demonstration employed 10 tree planting groups as the experimental unit, the response variable used was the number of surviving seedlings/the number of planted seedlings for each planting group. This group survival response variable was modeled as a function of weed control as a fixed main effect (with three levels) and stand as a random effect. An alpha level of 0.05 was used as the benchmark for statistical significance. Given that monsoon season survival data spanned only 4 months at the time of analysis, separate analyses were performed for each planting season. Statistical comparisons of survival among the planting seasons will be more appropriate when yearly data for both treatments become available.

RESULTS

The average survival rate after 13 months for the dormant season planting was 26 percent. Survival varied somewhat by weed control treatment, with PWC having statistically higher survival rates (34 percent) than the other two treatments (23 percent for NWC, 22 percent for CWC) when averaged across all stands (fig. 4). There were no statistical differences in survival between CWC and NWC. Evidence suggests that about 15 percent of the seedlings that did not survive, or 9 percent of all planted seedlings, were lost to desiccation after 13 months. The majority of the mortality was due to below-ground herbivory, likely from pocket gophers (*Thomomys* spp.), which, along with some above-ground browsing, occurred in all stands.

The average survival rate after 4 months for the monsoon season planting was 14 percent. Survival varied somewhat by weed control treatment, with PWC having statistically higher survival rates (25 percent) than the other two treatments (9 percent for NWC, 11 percent for CWC) when averaged across all stands (fig. 4). There were no statistical differences in survival between CWC and NWC. Evidence suggests that about 10 percent of the seedlings that did not survive, or 8 percent of all planted seedlings, were lost to desiccation after 4 months. Similar to the dormant planting, the majority of the mortality in the summer planting has been attributed to gopher herbivory which, along with some above-ground browse, occurred in all stands.

DISCUSSION

The survival rates observed in the planting demonstration were poor, and comparable survival rates have been documented elsewhere in the Southwest under similar conditions. Ouzts and others (2015) reported a 25 percent survival rate for planted ponderosa pine seedlings after 5–8 years across several southwestern stands, and rates from 0–12 percent in 38 percent of stands surveyed. The frequency of planted seedlings completely lost to herbivory in the planting demonstration suggests that it is the principal short-term obstacle to successfully restoring ponderosa pine in the Davis Mountains. Pocket gopher herbivory of planted seedlings is common in many parts of the ponderosa pine range (Barnes 1978, Dingle 1956, Hooven 1971). The survival rates in the planting demonstration (dormant season: 22–34 percent, monsoon season: 9–25 percent) are comparable to the 35 percent survival rates reported by Hooven (1971) after 1 year in areas occupied by pocket gophers. Hooven (1971) reported that survival rates had dropped to 12 percent after 5 years in those areas compared to 87 percent in areas without pocket gophers.

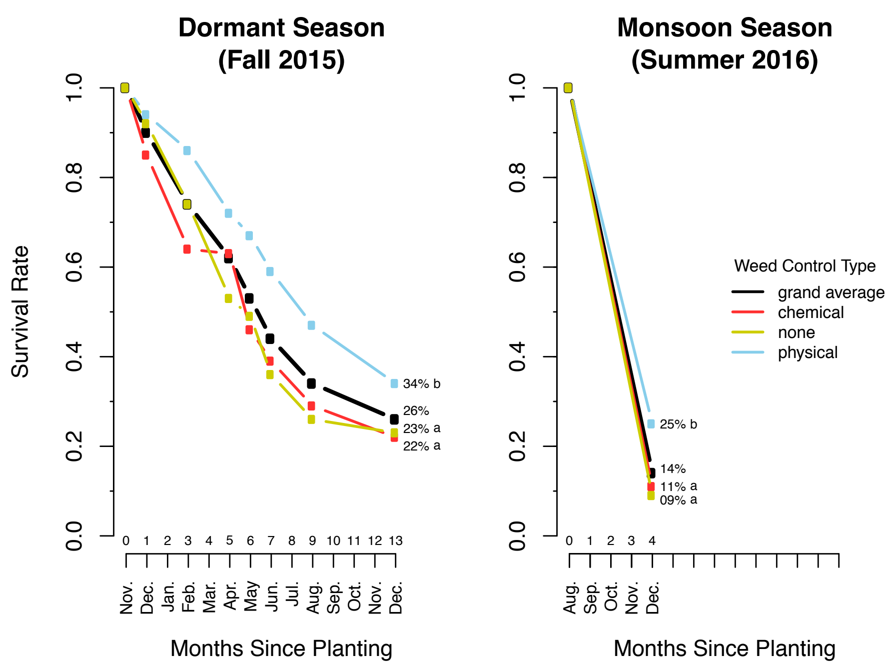

Figure 4—Longitudinal survival curves for the planting demonstration. Treatment means with different letters were statistically different (α = 0.05) within a planting season. For the dormant season (left), survival in the Physical Weed Control treatment was statistically greater than both the Chemical and No Weed Control treatments after 13 months. There was no statistical difference in survival between the Chemical and No Weed Control treatments after 13 months in the dormant season planting. In the monsoon season planting (right), survival in the Physical Weed Control treatment was statistically greater than both the Chemical and No Weed Control treatments after 4 months. There was no statistical difference in survival between the Chemical and No Weed Control treatments after 4 months. The vast majority of seedlings lost were attributed to below-ground herbivory, likely from gophers. Note: statistical differences do not necessarily indicate meaningful biological differences.

Successful restoration appears to hinge on identifying treatments to reduce below-ground herbivory, particularly in areas with very loamy soils where herbivory appeared more prevalent. Unfortunately, many common control strategies are seldom effective or feasible without intensive maintenance (Godfrey 1987, Hooven 1971). The higher survival found in the PWC treatment may be attributable to some deterrence offered by the two landscaping staples used to fasten the fibrous mats around the base of seedlings in the PWC treatment. Additional research into the efficacy of this and other below-ground herbivory reduction alternatives in the Davis Mountains Preserve is warranted, and a pilot case study has been planned.

Absent effective deterrence, a less desirable option may be an attempt to compensate for herbivory losses by planting substantially more seedlings than are ultimately desired. Based on the survival rates in the planting demonstration this would mean planting *at least* five times more seedlings than desired. This highlights the second obstacle to restoring ponderosa pine in the Davis Mountains: scarcity of seedlings from both natural and artificial sources. This is in stark contrast to portions of the ponderosa pine range like the Black Hills region where excessive reproduction densities are often a concern (Sheppard and Battaglia 2002). To date, cone and seed collection efforts have been limited to trees and stands within the immediate region of the planting demonstration. Managers may need to consider broadening the seed sources and relying on genetic diversity to allow some individuals to prosper in harsh sites.

The U.S. Forest Service has reported success with summer plantings in Arizona and New Mexico, coinciding with the monsoon season. The amount of desiccation after 13 months in the dormant season seedlings (~9 percent) was observed in only 4 months for the monsoon season seedlings (8 percent). The performance of the monsoon season seedlings 4 months after planting (fig. 4) suggests that monsoon planting is not a reliable option in the Davis Mountains at this time, but that cannot be claimed conclusively from the results as planting season effects were confounded by differences in planting stock (1-0 vs. 2-0), which is somewhat unavoidable when comparing planting seasons. Even in the nursery, the condition and survival of the locally-sourced 2-0 containerized seedlings used for the monsoon season planting were poor. Improved seed sources and nursery practices may yield better results during the monsoon in the Davis Mountains. However, in the immediate future, efforts may be better served by planting 1-0 containerized seedlings abundantly during favorable climatic windows. The results of the planting demonstration suggest that during El Niño years, dormant season planting could be a viable option if herbivory losses can be avoided. During non-El Niño years, the high winds and limited rainfall of the dormant season may be detrimental. Additional research into the season of planting is recommended.

It is possible that alternative timings, rates, or herbicides could provide more efficacious weed control while avoiding the adverse impacts on ponderosa seedling growth observed in the planting demonstration. Despite the precautionary efforts to minimize damage to the planted dormant season ponderosa seedlings during herbicide application, a few seedlings (10) exhibited some evidence of herbicide damage. Ponderosa pine has been identified as sensitive to several herbicides, including the one used in this application (Oust® XP) despite being labeled for use as herbaceous weed control for ponderosa pine. Continued investigation into the efficacy of alternative chemical weed control treatments with organized trials in the Davis Mountains is suggested.

Though below-ground herbivory has been identified as the principal short-term obstacle to regenerating ponderosa pine in the Davis Mountains, the larger question of ponderosa pine recovery, particularly if local climatic conditions become increasingly unfavorable, remains. Critical components of that question are the identification of target conditions that are both appropriate and achievable and the suite of management options, silvicultural treatments, and timings needed to meet them. The results of the planting demonstration presented here are an important first step in the development of science-based silvicultural guidelines for ponderosa pine restoration efforts in the Davis Mountains.

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