PONDEROSA PINE PLANTING: A SURVEY OF EXPERT KNOWLEDGE

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ABSTRACT

PONDEROSA PINE PLANTING: A SURVEY OF EXPERT KNOWLEDGE

BARNEY GREGG

Ponderosa pine forests in the southwestern US are at risk of conversion to other vegetation types due to slow natural regeneration. Artificial regeneration may be a viable tool to prevent the loss of ponderosa pine forests, but there is insufficient literature to guide effective planting. To address this gap, we interviewed researchers, forest managers, and nursery managers to gather expert knowledge to guide future reforestation projects and identify future research areas. We focused on four themes: seed sources, nursery operations, site preparation, and planting operations. Interviews with nineteen planting experts in the Southwest showed that all respondents knew the origin of their seed sources but had differing views on the appropriate level of site specificity for genetic adaptation. Challenges of ensuring appropriate seed sources included limited seed selection, periodicity of masting species, limited funding, and lack of a seed collection program. In the nursery, use of containerized seedling and treatments was considered by respondents to increase success. Site preparation treatments were used by most respondents but there was no consensus on the effectiveness of specific treatments. When outplanting, tree shelters received mixed reviews. Best planting times also had mixed responses between summer monsoon and fall seasons. Expected mortality was highly variable with 50% being the average. Desired eventual stand density ranged from 15 to 200 trees per acre. Grouped planting designs are increasing in popularity, but a few respondents still use grid designs. The use of nurse structures had positive effects. North and east- facing aspects showed to have greater success in comparison to south and west-facing aspects. Contractors are used and

preferred for planting because of their ability to bring in big crews. Short-term budgets limit flexibility of project planning and managers to a short window for reforestation.

The results of this study are directly relevant to management of future planting projects and suggest the areas that need more systematic research. Artificial regeneration is a critical tool for addressing the challenges of severe disturbance and warming climate. Expert opinions contribute valuable and timely knowledge for sustaining forest ecosystems in the Southwest.

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PREFACE

This study of ponderosa pine artificial regeneration in the southwestern U.S. was inspired by lack of literature on this topic. While natural regeneration has been studied, I was interested in finding out the factors that promoted success in artificial regeneration. This paper is intended for those involved in planting and reforestation management and research, specifically in the Southwest.

Chapter 1 Introduction

Forest fires have increased over the past few decades in the western United States, in terms of their size and severity due to climate change (Mueller et al. 2020; Singleton et al. 2019) and previous land management activities (Brown et al. 2019; Korb et al. 2019; Westerling et al. 2006). In the ponderosa pine (*Pinus ponderosa* Laws) forests in the American Southwest, management for livestock grazing, logging, and fire suppression have resulted in the exclusion of fires for the past century (Fulé et al. 1997). The outcome of this type of management is uncharacteristically high tree density and heavy fuels (Brown et al. 2019; Fulé et al. 1997). Increased forest mortality is expected to continue with projected climate warming (Steiger et al. 2019; Williams et al. 2013). Replacement of forests through natural or artificial regeneration is therefore an issue of growing importance.

Ponderosa pine trees do not have serotinous cones or sprouting capacity and seeds are not stored in long-term seed banks either in the soil or the canopy (Oliver and Ryker 1990; He et al. 2012). These characteristics of ponderosa pine limit natural regeneration after a severe burn (Ouzts et al. 2015). Natural regeneration is increasingly limited by drought, warmth, and disturbance, causing increased forest mortality(Haffey et al. 2018; Savage et al. 2013). With high severity fires creating large patches of dead trees (Bonnet et al. 2005) beyond effective seed dispersal range, natural regeneration is highly unlikely within these burned areas beyond 200 meters from live tree seed sources (North et al. 2018). Even within the effective dispersal range, natural regeneration is still highly variable, suggesting factors other than seed source are critical (Owens et.al 2020; Petrie et al. 2017; Stoddard et al. 2018; Rodman et al. 2020). Artificial regeneration relies on the practices important to planting success: selection of appropriate seed source, storage, nursery operations, site selection, timing, and methods of planting, with consideration for the presence of competing vegetation (Schubert et al. 1970; Heidmann 2008; Pinto et al. 2011).

Previous research in the southwestern U.S. has largely focused on natural regeneration, with the notable exception of "Post-fire Ponderosa Pine Regeneration with and without Planting in Arizona and New Mexico" (Ouzts et al. 2015). While numerous individual experts manage nurseries and conduct planting operations, with support from geneticists and researchers in the resource management agencies, there is a lack of systematic, consolidated information based on the accumulated knowledge of experts for understanding which factors should be considered in artificial regeneration.

This study aims to fill the gap in our understanding of the factors promoting artificial regeneration where academic studies are lacking. This research draws on expert knowledge of professionals engaged in nursery production and out-planting of ponderosa pine in the Southwest. This approach analyzes experience and expert opinions from field observations by reforestation practitioners across the Southwest that are not published in literature. We specifically assess the following four aspects of artificial ponderosa pine regeneration:

1) How does seed source affect the success of artificial ponderosa pine regeneration?
2) In what ways do nursery operations affect the success of artificial ponderosa pine regeneration?
3) Is artificial ponderosa pine regeneration success increased by site preparation?
4) Do planting methods differ and how do they affect artificial regeneration in the Southwest?

Chapter 2 Methods

Study area

The study area comprised the ponderosa pine forests in the Southwest. For this study, the "Southwest" includes Arizona and New Mexico, southern Utah and Colorado, and far west Texas (Fig. 2.1). The population of the study was researchers, forest managers, and nursery managers in the Southwest who have experience conducting research on planted ponderosa or have planted ponderosa pine.

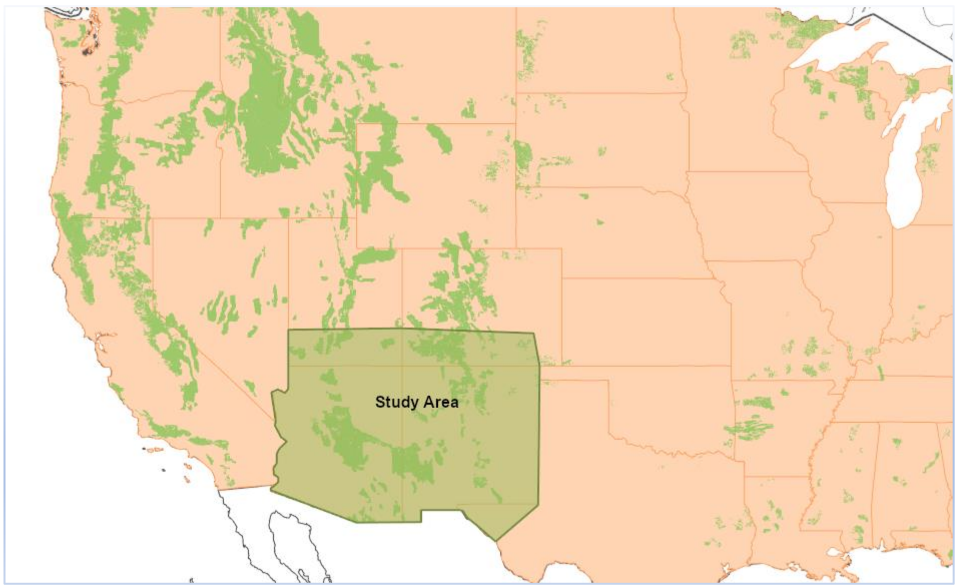

Figure 2.1. Study Area Map (labeled polygon), other areas in green are lands managed by the US Forest service.

Interview questionnaire design for structured expert interviews

This research employed qualitative, semi-structured in-person interviews of researchers, nursery managers, and forest managers with experience in planted ponderosa pine in the southwestern United States via Zoom. A semi-structured interview was used to address variables of interest while attaining lived experiences (Galletta 2013). The interview questionnaire was constructed based on a systematic literature review of natural and artificial ponderosa pine regeneration.

We began with a literature review to inform the research questions and construct prompts to guide the respondents to articulate their experiences in an organized manner. To identify factors promoting reforestation success, we searched all the published papers in the Web of Science database using search strings of (ponderosa pine) AND (southwest) AND (planting or reforestation or regeneration) in the title, abstract and keywords (Topics).

After examining abstracts of all 49 studies, we focused on the subset that addressed the importance of factors affecting regeneration, conditions that promoted regeneration, climate change effects to forest structure and replanting efforts, and time since wildfire. We selected seven studies to analyze and code using inductive coding with a hierarchical coding frame in NVivo (Gibbs 2014). Utilizing hierarchical coding, we placed ponderosa pine regeneration as the top-level code, steps in artificial regeneration (seed source, nursery operations, site preparations, and outplanting) as mid-level codes, and factors (e.g., seed storage, climate change, containers, tools, and planters) as the third level code (Fig. 2.2). We created a structured interview questionnaire based on this hierarchy.

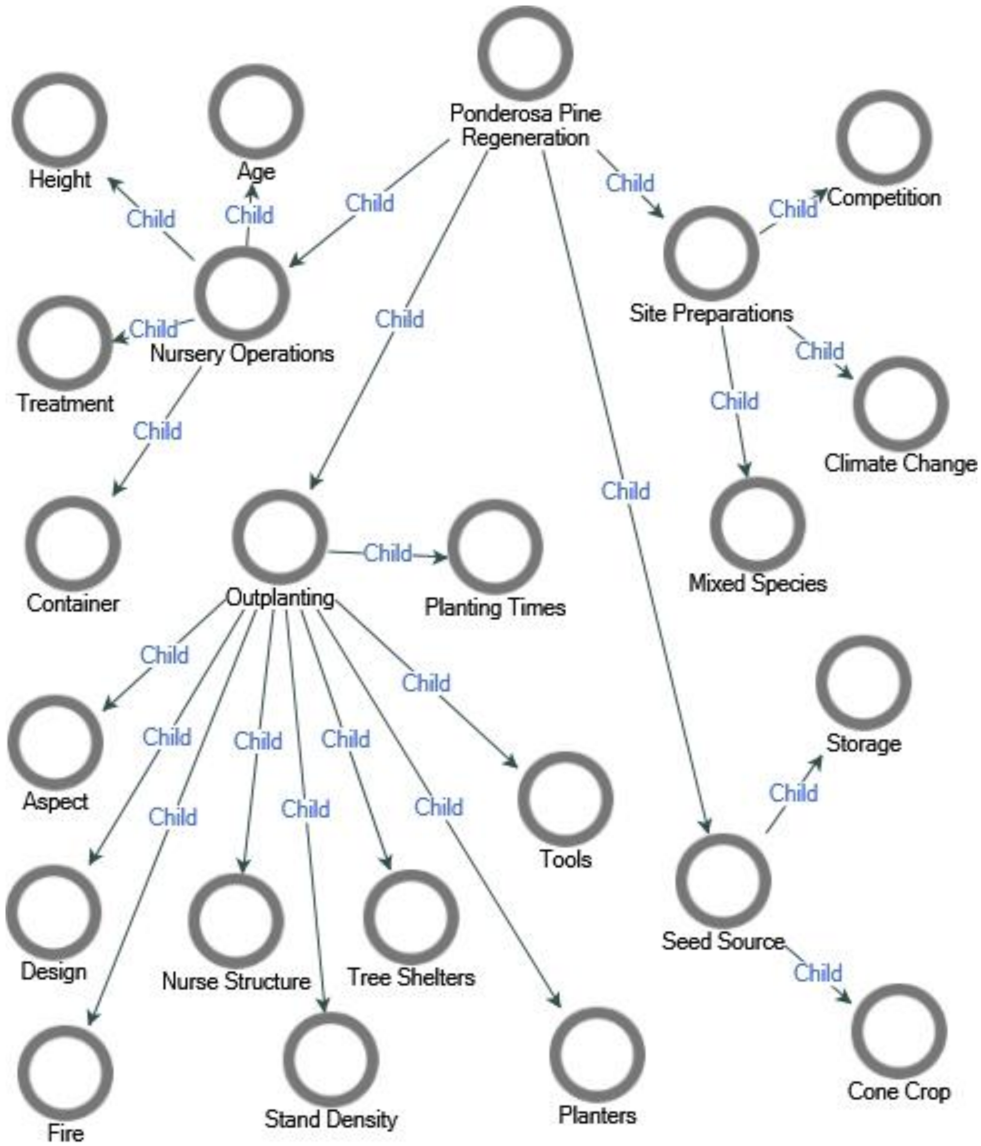

Figure 2.2. Hierarchical codes of the literature review.

A questionnaire was created and pilot-tested with an expert in reforestation at Northern Arizona University (NAU) and we revised the question structure and wording based on the comments and suggestions of the expert. The final questionnaire contained eight sections and had an estimated completion time of 1 hour. The interview questions are attached in Supplemental Information. The interview questionnaire and plan were reviewed and approved by the NAU Institutional Review Board on Human Subject Research (1599368-1). The research was classified as minimal risk. We followed the university´s data collection guidelines to protect the privacy of the respondents and stored the data without identifiers.

The interview questionnaire started with a brief overview of the project, a verbal consent to participate and to be audio recorded, and to ensure that respondents meet the consenting age requirement and understand how the data would be handled and analyzed. We also asked appropriate screening questions to ensure only the targeted population completed the interview. Expert sampling is a type of purposive sampling which calls for experts in a particular field, in this study, reforestation, so background information and experience with ponderosa pine was required. This form of sampling has an advantage over other nonprobable sampling when observational evidence in the field of study is lacking (Etikan et al 2016). We asked the respondents: 1) type of their job (e.g., researcher, nursery manager, or forest manager); 2) specific job title and the type of employers (federal, state, tribal agencies, academic institutions, NGOs and others); and 3) their experience with artificial regeneration. There were no minimum years of experience in order to participate. The mid-level codes from the literature review were used to construct specific questions about seed source, nursery operation, site preparations, and planting method and cost.

Regarding seed source, we asked respondents if they knew the origin of their seeds and the process of selecting seeds in their projects, e.g., agency guidelines, expert advice, or personal choice. Next, we asked respondents if they think seed source affects seedling survival and the reasons for their opinion. This allows the participant to give their expert opinion based on observations in the field. Lastly, we asked about challenges in seed selection methods, how those challenges affected success, and how they think those challenges can be addressed.

On nursery operations, we asked which seedling is preferred in the Southwest, i.e., bareroot or containerized. If they used containerized seedlings, we followed up on container details. We asked about issues related to the supply, quality, and source of seedlings, nursery treatments, and the age and height of seedlings at outplanting.

We asked about the site preparation methods, respondents' view on potential impacts of climate change and their influence on site selection. We asked the respondents if they make any site preparation prior to planting, how they decided to use the site prep methods, if they think the site preparations affect survival, and if so, how. We asked for their perspective on climate change and its influences on site selection. Finally, we asked if mixed species planting should be considered, using examples such as adding mixed conifers to higher elevation sites or pinyon to lower elevation site.

We asked about outplanting methods in terms of uses of tree shelters and nurse structures, spatial patterns of planting, density of seedlings (number per acre) as well as target stand density and expected rate of mortality. Regarding outplanting operations, we asked who plants the seedlings, if they are from the Southwest region or not, the tools used and preferred, and cost of the project per acre.

We concluded the interview with an open-ended question to obtain information about other factors affecting success of reforestation projects that were not mentioned in the interview. This section allows the respondents to explore those factors not previously identified but are thought to be important to the success of reforestation. The respondents were asked if they knew anyone else who may meet the criteria for the interview for snowball sampling (Biernacki and Waldorf 1981).

Recruitment

The study population was identified initially as all the authors and co-authors of published papers in the literature reviewed, forest managers in the public land management agencies, and tribal forest managers on Native nations who have experience in ponderosa pine reforestation projects in the southwestern United States. Purposive and snowball sampling were used for recruitment. Purposive sampling, which is non-random and has inclusion criteria, (Etikan et al. 2016) was used to sample only individuals that have worked in planting ponderosa pine. Snowball sampling yields study samples through referrals from those who know others with characteristics related to the research topic, (Biernacki and Waldorf 1981) and was used to reach a small, specific group of experts for our study population.

To reduce nonresponse error, both email and telephone calls were used as modes of contact (Dillman et al. 2014). Forty-one experts were sent a personal email invitation, and those who were interested in participating were then sent an informed consent via email with the study details. Nonrespondents were sent a follow-up email 3 weeks after the first email, and then a phone call invitation 2 weeks after the follow-up email if there was still no response.

Interview procedures

We conducted the semi-structured in-person interviews via Zoom between July and October 2020. The average time for interview completion was one hour and six minutes. Some limitations of video-call interviews include the need for reliable internet or mobile service, scheduling the time of the interview, and potential interruption during the interview. However, video interviews provide data quickly upon completion and capture in-depth responses that provide high quality data (Dillman et al. 2014). Video or call was necessary due to travel limitations and Covid-19 restrictions. We chose not to do a web-based survey due to the limitations of scaler questions to elaborate on expert opinions of the factors being analyzed.

Data analysis

The recorded interviews were transcribed using Otter.ai, which we reviewed for spelling and other potential errors, and uploaded transcriptions to NVivo. We analyzed the responses using descriptive coding in NVivo, which summarizes the primary topic of each excerpt (Saldaña 2015). We placed the codes in a hierarchical framework which groups third-level codes (i.e. factors) under broader mid-level codes (i.e. steps in artificial regeneration) which are linked to the top-level code (i.e. artificial ponderosa pine regeneration) (Wiltshier 2011). This allowed us to determine which factors affects success in each step of artificial regeneration based on expert opinions. Many respondents have experience with multiple agencies in different positions over the years and did not base their responses on any particular agency. Rather, the interviews were completed based on previous and current experiences, and respondents could not be categorized by agency or job titles. Because the respondents were not categorized, each respondent was given a letter (R) and an individual number(1-19).

Chapter 3 Results

Using the two modes of contact for recruitment, 19 experts completed the interview. The experts interviewed represent universities (5), federal (10), state (3), tribal agencies (7), and private business (1), and a range of different positions, such as forest managers (13), nursery managers (4), and researchers (6) in the Southwest. The totals add to more than 19 because several respondents have experience in more than one role and organization. Their experiences with ponderosa pine planting range from one to 40 years.

Seed Source

When selecting seeds used for planting, respondents are guided by personal choice, agency guidelines, expert advice, and available seeds (Table 3.1).

Table 3.1. Seed source selection and level of genetic adaptation perspective by respondents

	Level of Genetic Adaptation		
Selection	Site Level	Local level	Elevational and Latitude level
Guidelines +Personal Choice (n=5)	3	2	
Guideline + Personal Choice + Expert Advice (n=4)	1	1	2
Guidelines + Expert Advice + Personal Choice + Available Seeds (n=3)	2	1	
Guidelines+ Expert Advice (n=3)	1	1	1
Guidelines (n=2)	2		
Guidelines + Personal Choice + Available seeds (n=1)	1		
Guidelines + Available Seeds (n=1)		1	

Although combinations of the four were used to select seeds, guidelines and personal choice (n=5) and guidelines followed by expert advice and personal choice (n=4) were the most common. All respondents knew the origin of their seed sources down to the elevational and latitudinal band from where they were collected. All respondents stated that proper labeling using elevational and latitudinal bands allows seeds to be used in other projects that match these labels. Fourteen respondents collected their own seeds and could track seed sources down to a general location. Views on level of genetic adaptation of seeds varied by respondents. Ten respondents considered seeds to be most closely genetically adapted to conditions at the site level, while others state more broad adaptation at the regional level (n=6) and at the elevation and latitudinal level (n=3). Six respondents consider seeds to be maladapted due to change in site conditions following a wildfire and suggest assisted migration to be considered.

The biggest challenges stated by respondents are limited funding for collecting seeds, periodicity of cone crop, inadequate infrastructure for seed storage, and limited selection in seeds (Figure 3.1). Two respondents stated that inflexible agency-specific guidelines have been a challenge, because they do not allow assisted migration. Respondents noted that ponderosa pine does not produce a cone crop every year, limiting the number of seeds to choose from. Some pointed out that even in years when cone crops are ready, most departments lack sufficient funding for collection and storage infrastructure.

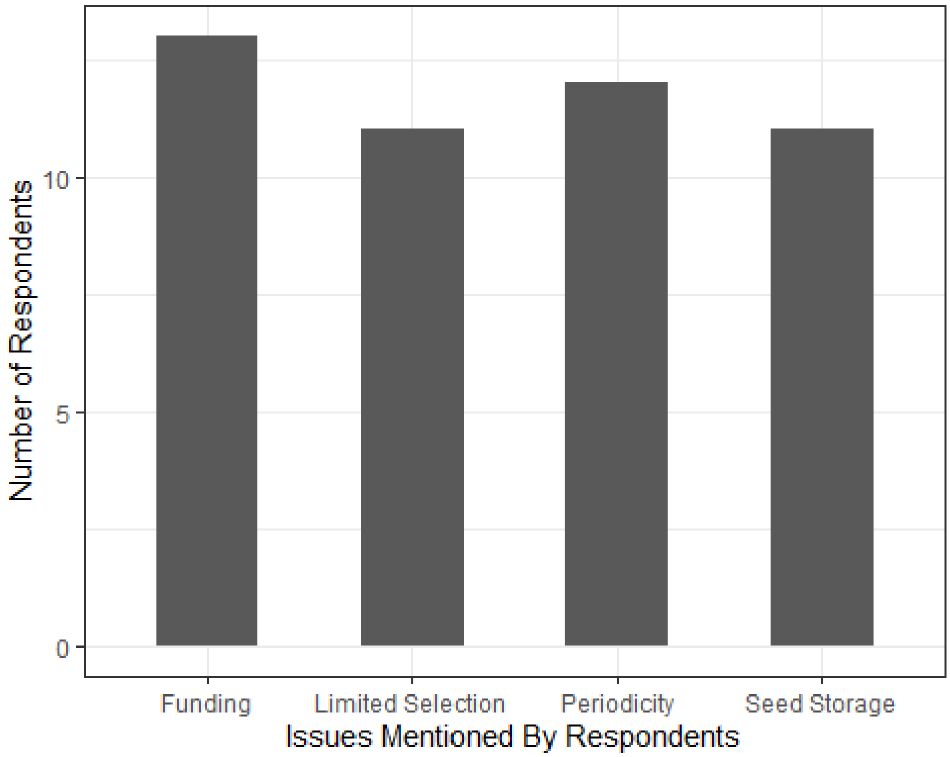

Figure 3.1. Top challenges described by respondents for seed selection.

All respondents suggested that the first step is reallocating funding to reforestation projects and creating a seed collection program. Respondents mentioned that it would allow for monitoring the forest for mast years when a bumper crop is produced, collecting cones prior to wildfires, increasing capacity of seed storage and selection, training personnel for cone collection, and seeking outside funding and community involvement.

Nursery operations

When inquiring about nursery operations, respondents were asked about stock type, seedling age and height, and treatments. Containerized seedlings are used and preferred over bare-root seedlings by all respondents (Fig. 3.2). One respondent stated, “If we plant bare-root trees, they just simply don't work.” The common reason for containerized seedlings mentioned by respondents is that they have growing media intact with the roots, protecting seedlings from root damage and providing nutrients when seedlings are being established. The most common container sizes are 8 and 10 cubic inches, and range between 8 and 40 cubic inches. Five respondents stated that container sizes are selected based on soil depth at their project site and used larger containers for the sites with deeper soil.

Figure 3.2. Containerized seedling which has growing media intact with the roots when planted. Photo provided by respondent R4.

The majority of respondents (n=16) stated that they had no issues related to the supply and quality of seedlings received. However, two respondents did state that they have received fewer seedlings than requested from the nursery due to poor germination of older seeds. One respondent also stated that they received seedlings that had fungus growing on them upon arrival, resulting in the loss of half the seedlings needed for their project.

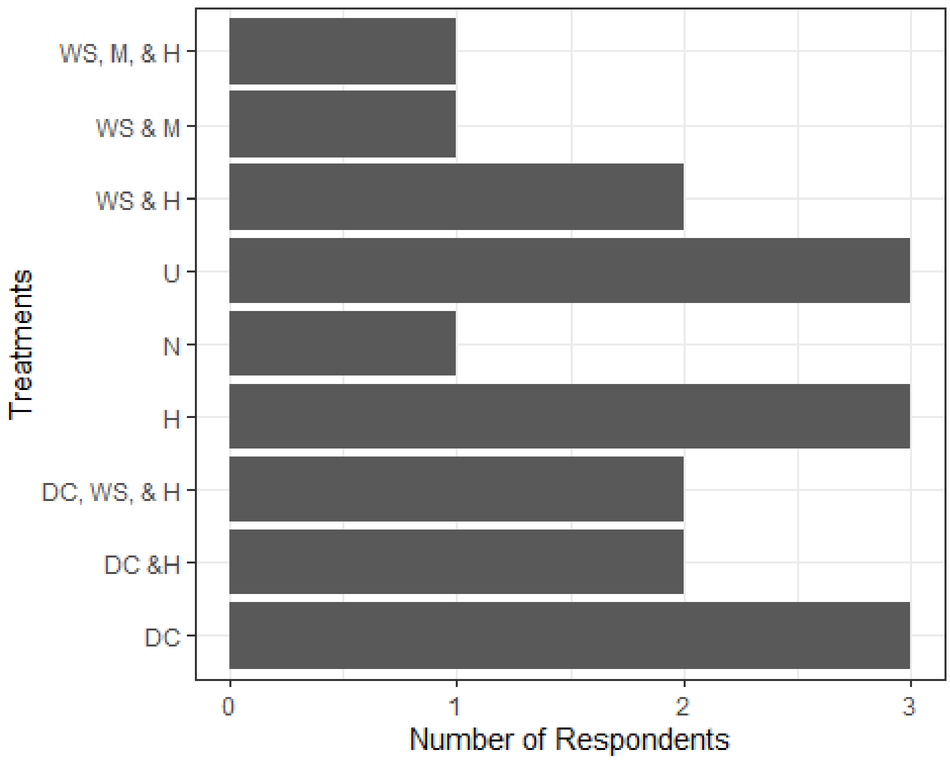

Figure 3.3. Nursery treatments used by respondents, DC= drought conditioning, H= hardening off, WS= water stress, M= mycorrhizae inoculations, N= no treatment, U= unsure if treatments were used.

Treatments used at the nursery to manipulate seedling physiology and morphology were described by 14 respondents (Figure 3.3). Only one treatment was used by 6 respondents and in various combinations by 8 respondents. Eight respondents stated seedlings that have undergone hardening off, drought conditioning, and water stress treatments have increased survival when compared to untreated seedlings. Mycorrhiza inoculations were used by 2 respondents and it is unclear whether this treatment increased the rate of survival. Table 3.2. summarizes the common processes and desired outcomes of different nursery treatments.

Table 3.2. Nursery treatments that can be applied to tree seedlings to enhance reforestation success.

Treatments at the nursery	Process	Desired Outcome
Hardening off	Remove seedlings from greenhouse in last month to adjust to ambient temperatures	Formation of a hardened, woody stem
Drought conditioning	Water stress seedlings right after germination up until departure from the nursery	Drought resistance in seedlings
Water stress	Water stress seedlings during the last month at the nursery	Formation of a hardened woody stems and dormant bud
Mycorrhizae inoculation	Inoculate growing media at the nursery	Formation of a symbiotic association between seedling roots and fungi

Seedlings used for outplanting range between 4 and 16 months old (Figure 3.4). The most common age range used for outplanting was between 6 and 12 months old. There was no consensus on whether seedling age makes a difference on the survival of seedlings. Only 5 respondents mentioned planting seedlings of different ages. Two of these respondents reported greater success with older seedlings; two respondents could not determine if the survival rate was based on the environmental conditions or the age of seedlings, because only one age class was used at a time; and one respondent had the same survival rate regardless of the age of seedings.

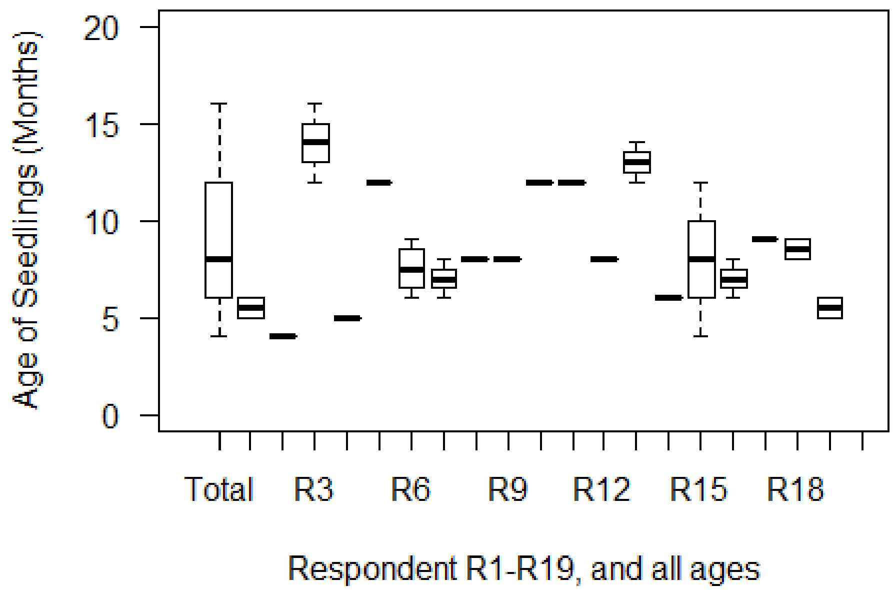

Figure 3.4. Age ranges of seedlings mentioned for outplanting by respondents (R1-R19). The first boxplot (Total) is all the ages combined to display overall age range mentioned for outplanting.

Seedling heights ranged between 3 to 12 in, with 6 to 10 in being the most common range used for planting (Fig. 3.5). Three respondents stated that shorter seedlings do poorly in sites with high vegetation competition, and 3 respondents stated taller seedlings need more water. Fourteen respondents mentioned root to shoot ratio is a better indicator of seedling survival than seedling height, preferring larger root mass than above ground mass. One respondent stated, “More roots mean… you have a longer period of time that that seedling can sustain a lack of water.”

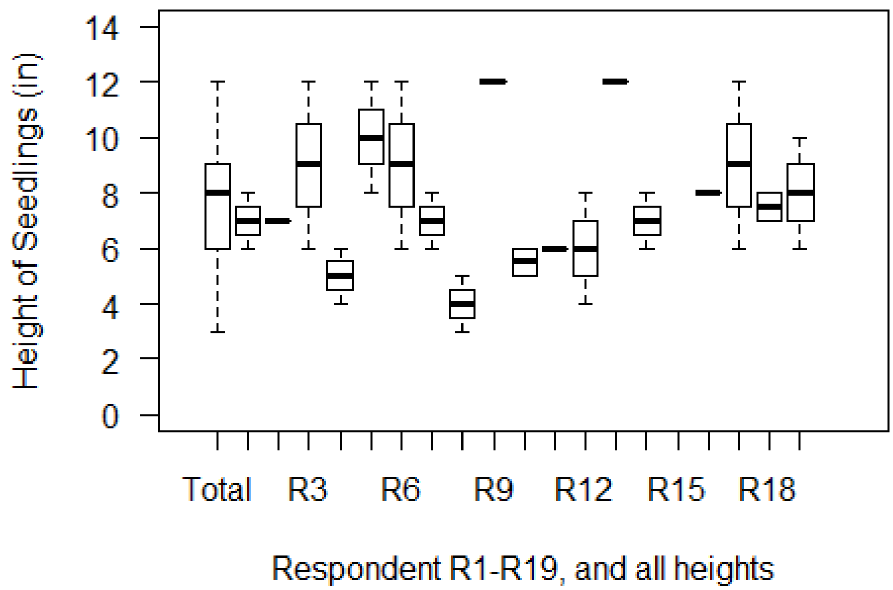

Figure 3.5. Height ranges for seedlings mentioned for outplanting by respondents (R1-R19). The first boxplot (Total) is all the heights combined to display overall height range mentioned for outplanting.

Site preparations

Respondents were also asked about site preparations. Site preparations are done prior to planting, with activities that can include scalping the forest floor, spraying herbicides, salvage logging and felling dead standing trees, mastication, and prescribed burning (See Table 2.2 for the details of these treatments). Fifteen respondents used at least one of these methods based on site conditions (Fig. 3.6). Respondents stated that scalping, herbicide applications, and prescribed burns are sometimes applied at sites with high grass cover.

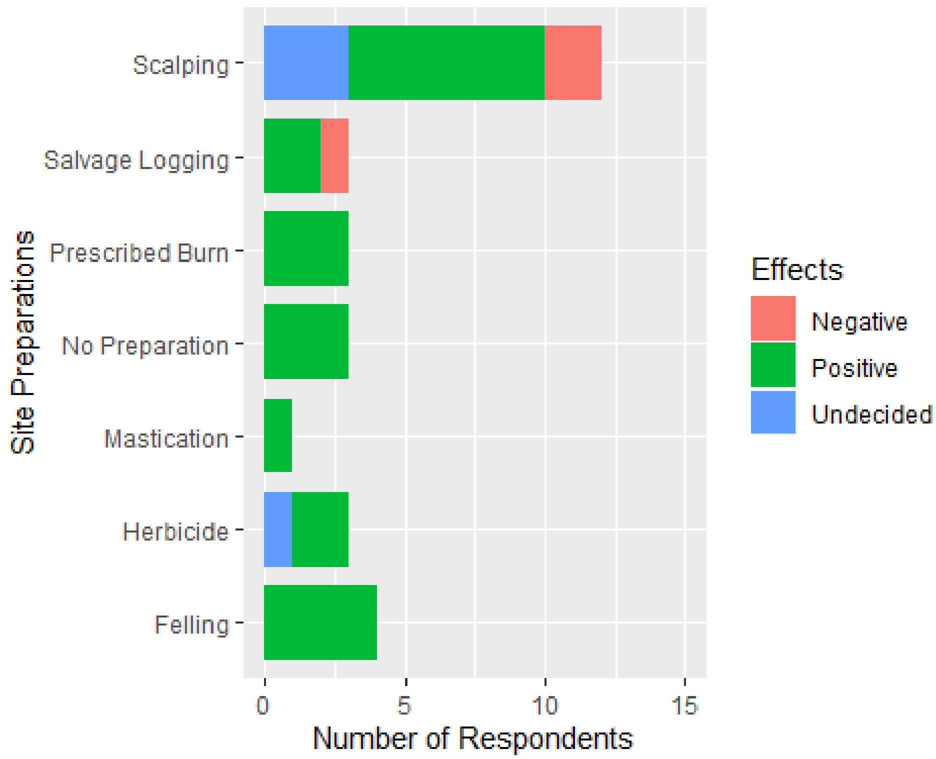

Figure 3.6. Site preparations by the number of respondents that have experience using them and their reported effects.

Scalping radii ranged from 6-36 in during planting operations around each seedling at a depth of 1 to 2 in. Twelve respondents used this method and 3 of these respondents were unsure if scalping had any effects. Two reported that scalping had a negative effect by increasing moisture lost when bare soil is exposed to the sunlight and facilitating species were removed. The other 7 stated that it had a positive effect by decreasing competition. Herbicide application was used by three respondents. One respondent that used this method was unsure if herbicide application was beneficial while the other two reported a positive effect. Table 3.3. summarizes the common definitions of the terms used to describe site preparation Prescribed burns were used by three respondents which stated positive effects by removing competition and large woody debris, reducing potential for reburn.

Mastication was used by only 1 respondent reporting a positive effect but suggested by two other respondents. Four respondents used felling methods for safety purposes, erosion control, and salvage logging with positive effects.

Table 3.3. Preparation methods that can be applied to sites to enhance reforestation success.

Site preparations methods	Definition	Used for
Herbicide	A toxic substance used to destroy unwanted plants	Reducing grass competition
Scalping	Removal of forest litter or competing vegetation	Removal of competing grasses
Salvage logging	Logging of dead trees	Removal of dead trees
Prescribed burn	Planned burn used to meet management objectives	Removal of small vegetation and coarse wood
Felling	Cutting down of trees	Microsite creation and erosion control
Mastication	Reduction of vegetation into small chunks	Reduction of small competing vegetation and mulching

Respondents were also asked about effects of climate change on planted ponderosa pine seedlings. Their responses included changes in monsoonal events, maladaptation, rising temperature, longer periods between cone crop, encroachment and forest conversion at the lower sites, insect outbreaks, and increase drought periods (Fig. 3.7). All the effects are viewed as negatively impacting planted ponderosa pine. Two respondents consider the effects of climate change when selecting sites. Seven respondents suggested diversifying seed sources including uses of more drought tolerant species from lower elevations to increase the rate of survival under the impacts of climate change.

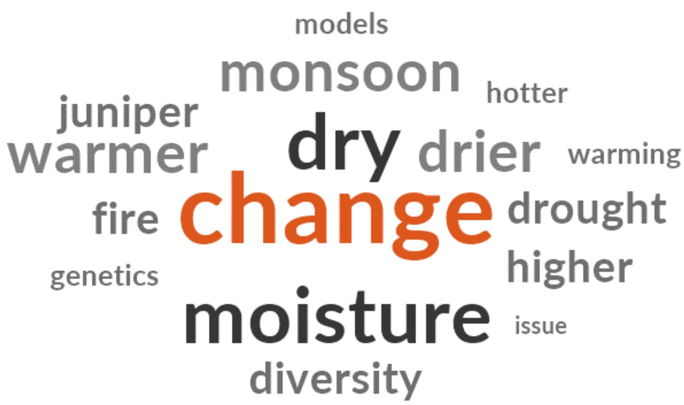

Figure 3.7. Word cloud of frequently used words when talking about climate change.

Respondents were asked if mixed species planting should be considered in ponderosa pine sites. Fourteen respondents stated that mixed species planting should be used to diversify the forest, which will increase resilience. One respondent argued that, “With two species, if one species is attacked by some insect or disease, you've got the other ones still.” Nine of the 14 respondents stated that mixed species planting should only be used in higher elevation sites due to encroachment of juniper and pinyon at lower sites. Five respondents stated that planting mixed species should not be used at both high and low elevation sites because of increased competition and added fuels.

Planting operations

Fifteen respondents have experiences using tree shelters for planting (Table 3.4). Those who have not used shelters stated that their reasons for excluding them were cost, mixed results from other projects, great survival without shelters, and research objectives that did not involve them. The most commonly mentioned advantages of shelters were protection from animal browsing and microclimate creation. Other advantages were shading, ability to reuse the shelter, and increased soil moisture.

Table 3.4. The pros and cons of using tree shelters stated by respondents and their recommendations.

Use of Tree Shelters	Positives	Negatives	Recommendations
Yes (n=15) No (n=4)	Browse protection (n=11) Microclimate creation (n=6) Reusable (n=2) Provides shade (n=2) Increase moisture (n=1)	Expensive (n=15) Difficult remove (n=11) Difficult to install (n=9) Overheats seedlings (6) Entanglement (n=6) Aesthetics (n=4) Maintenance (n=3) Nonbiodegradable (n=3) Non-rodent proof (n=2) Promotes grass growth (n=1)	Yes (n=2) Yes with condition (n=8) No (n=5) unsure (n=4)

*Frequencies of descriptive words by respondents

Disadvantages of using tree shelters include increased costs, difficulties with installation, difficulties with removal, and overheating seedlings. Other disadvantages include entanglement of the seedling, aesthetics, maintenance, non-biodegradable material, lack of protection from rodents, and increased grass growth within the shelter. One respondent stated, “I would prefer to plant more trees and have higher mortality... than to put all this plastic trash out on the landscape... then we have all this garbage out there.” Fifteen respondents mentioned that the cost of planting projects using tree shelters in many cases doubles or triples the overall cost. Four respondents mentioned the negative effects of shelters on aesthetics. Two respondents recommended use of tree shelters, 5 did not, and 4 were unsure. Eight respondents noted the use of shelters would only be beneficial in areas with high browsing pressure or for small projects.

Natural structures, such as rocks and logs, also known as nurse structures, were used by 17 respondents (Table 3.5). Noted positive effects of nurse structures are outlined in the table below.

Table 3.5. The pros and cons of using nurse structures stated by respondents and their recommendations.

Use of Nurse Structures	Advantages	Disadvantages	Recommendations
Yes (n=17) No (n=2)	Microsite (n=7) Shade (n=7) Soil Moisture retention (n=6) Protection from browse (n=4) Protection from wind (n=2) Weed control (n=1)	Not always available (n=8) Training for proper use (n=7) Reburn potential (n=5) Cost (n=4) Live competition (n=3) Slows progress (n=2) Inspections (n=2)	Yes (n=14) Site Dependent (n=2) Unsure (n=3)

*Frequencies of descriptive words by respondents

Seven respondents mentioned that seedlings should be planted on the north side near the structure, which has the highest potential for shade, soil moisture, and microclimate. Eight respondents believe nurse structures increases seedling survival, and one mentioned that highest survival is found behind nurse structures. Disadvantages of using nurse structures are also outlined in the above table. Five respondents stated that using coarse wood as nurse structures can increase the risk of mortality if return occurs. Although nurse structures are considered free protectants, 4 respondents stated that some planters charge more for moving objects to these areas, increasing overall costs. Three respondents stated live nurse structures can compete with the seedling. Most respondents recommend nurse structures and 2 recommend it only for small projects, while 3 were unsure.

How seeds are planted in terms of spacing was of interest to planting operations to determine if there was an effect in different methods. Seedlings are spatially planted using one of two designs: grid, or group (Table 3.6). Grid design is done by spacing seedlings uniformly across the site, ranging from 8ft by 8ft to 20ft by 20ft. The range of seedlings planted per acre is between 109 to 520. This method was stated by one respondent as the least difficult to follow because seedling placement is done by a measurement rather than judgement. One respondent that used this method did not state their reason for using it. Two respondents used this design for their research purposes, and 2 were taught this method.

Table 3.6. Planting designs, spacing of seedlings, and reasons for design preference stated by respondents.

Planting Design (Respondents)	Spacing Mentioned	Reason for design and spacing
Grid (n=5)	4x4, 8x8, 9x9, 14x14, 15x15, 14x14	Research design (n=2) Expert Advice (n=3)
Group (n=14)	Spacing Vary (Target trees per acre)	Microsite (n=8) Seed source to Fill in Gaps (n=5) Mimic natural variation (n=6) Most productive areas only (n=8) Decrease fire hazard (n=3)

*Frequencies of descriptive words by respondents

The majority of the respondents have abandoned grid design planting and prefer group design (fig 3.8). Group design, also called Nucleation or groupy clumpy planting, is used to plant in groups, leaving unplanted area between groups. Group sizes vary from 4 trees up to 20 acres of planted trees. All respondents stated that seedlings are still spaced in an even fashion within groups. Seedlings planted per acre using this approach range between 100 to 400. Respondents stated this design creates islands of seedlings, mimicking natural regeneration, while reducing fire hazard. Thirteen respondents state that selectively planting the most productive part of the site while skipping undesirable areas, such as rocky ground, is an advantage of this design.

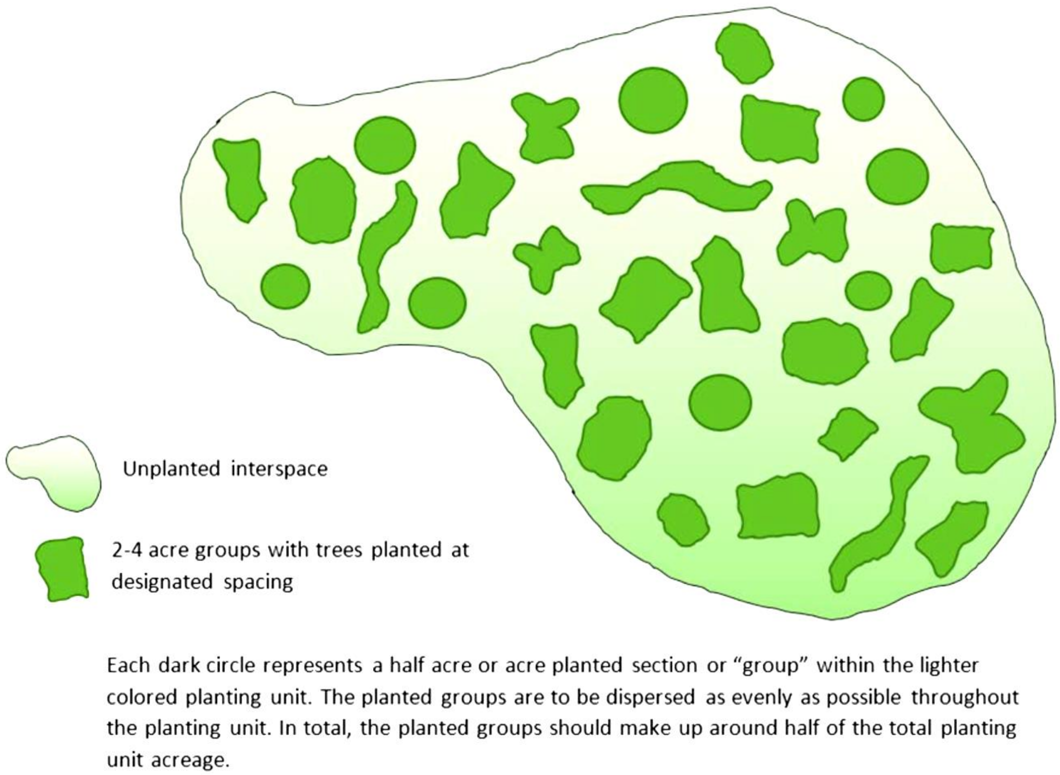

Figure 3.8. Example of group planting design. Picture provided by respondent R4.

Respondents were also asked about their expected mortality rates. Expected mortality of seedings ranged between 20% and 95% over the 18 respondents. The most commonly mentioned was 50%. One respondent could not determine the expected mortality due to lack of monitoring.

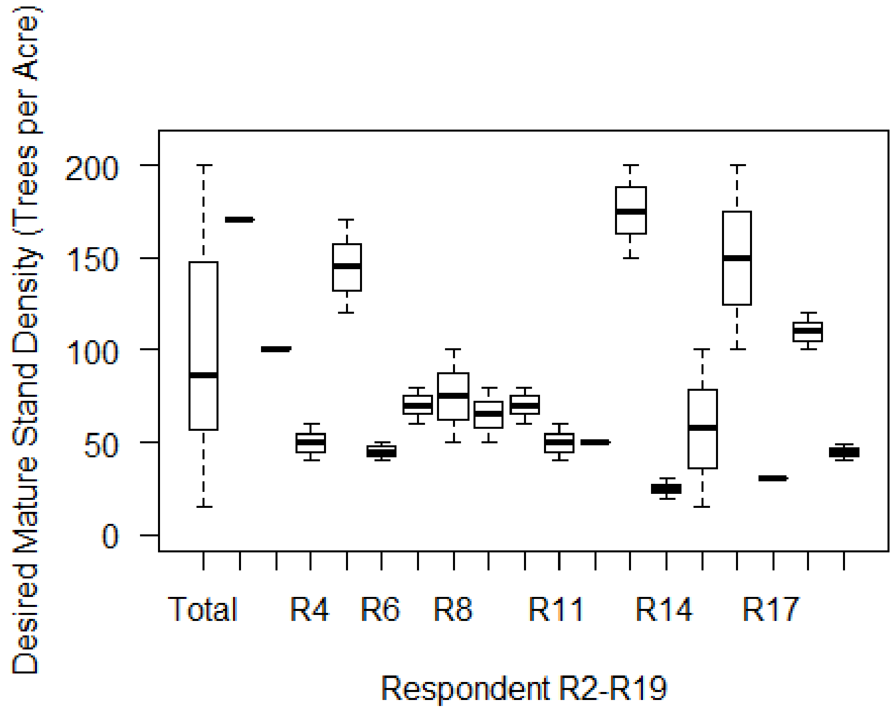

Figure 3.9. Desired eventual density mentioned by respondents (R2-R19). The first boxplot (Total) is all the stated desired densities by the respondents to display overall range.

The desired eventual density of the forest stand varies between 15 to 200 mature trees per acre by eighteen respondents (Fig. 3.9). One respondent did not answer. The average was 100 trees per acre with a median of 86.

The time and season for planting stated by all respondents were linked to current or expected soil moisture. Springtime planting is done in the months of March and April, monsoonal planting between July and August, and fall planting between September and November. Monsoon and fall plantings were the most common times used for planting by respondents. Eight respondents used strictly monsoon or fall seasons, and two respondents used both times for planting. Table 3.7 presents the factors affecting the choice of planting times.

Table 3.7. Planting seasons used and their advantages and disadvantages mentioned by the respondents.

Planting Seasons (Respondents)	Advantages	Disadvantages
Spring (n=1)		Snow (n=2)
Monsoon (n=10)	Soil moisture (n=6)	Variable (n=3) High evapotranspiration (n=1)
Fall (n=10)	Soil moisture (n=6) Dormant bud (n=4) Wettest period following (n=4) Low evapotranspiration (n=3) Low temperatures (n=2)	Frost heaving (n=1) Dry (n=1)

*Frequencies of descriptive words by respondents

Advantages and disadvantages of planting times varied amongst respondents. Six respondents stated that monsoon planting was used because of the expectation that soil would be moist, thereby increasing root development and stem growth. The challenges of using monsoon seasons were timing the rains, which have become irregular in this region. One respondent stated that soils dry quickly after the rains, limiting planting times. Soil moisture was also linked to fall planting by six respondents. Four respondents stated seedlings planted at this time were in a dormant state, and above ground growth is minimal. Winter is the wettest period following fall and helps seedlings carry over to the spring growing season. Some respondents stated that early freezes are a risk for mortality from frost heaving with fall planting.

Spring planting was used by one respondent because of soil saturation by snow melt. The respondent did state that spring was preferred because monsoons were becoming irregular in their region. However, dry months following planting were noted as problematic. Spring planting was not used by most respondents, and 2 stated that survival of seedlings was low because of late snowfalls during this season.

Table 3.8 presents the responses for appropriate planting time after a wildfire. Fifteen respondents recommend planting soon after a fire to prevent carbon and topsoil loss and selective planting in the areas not at risk of erosion or flooding. Four respondents suggested waiting would allow time for some natural regeneration.

Table 3.8. Planting time after wildfire suggested by respondents.

How long after wildfire should planting be done	Reasons	Recommended
Soon after	Low competition (n=6) Minimal scrap (n=4) Capture nutrient flushes (n=2)	n=15
Wait 4 plus years	Decease flooding and erosion (n=3) Natural Regeneration (n=3) Decrease browse pressure (n=1)	n=4

*Frequencies of descriptive words by respondents

Physical features of planting sites, such as aspect, were noted by the majority of respondents (n=16) as important to the success of planting (Table 3.9). Every time west-facing aspect was mentioned, it was in conjunction with south-facing aspect, as east-facing aspect with north-facing aspect. North and east aspects were associated with lower temperatures and more moisture and shade. Planting sites with north and east facing slopes were noted as having greater success in seedling survival by eleven respondents. In these sites, characteristics of microsites were not as critical as those with west and south facing aspect. However, sites with south and west facing aspects cannot be avoided in restoration projects (n=6). Degree of slope was noted as also crucial for the sites on south facing slopes as those with steeper slopes can get hotter (n=1). It was suggested that planting sites with southern and western aspects should include nurse structures. Few respondents have not studied aspect and were unsure of its effects (n=2) or stated other factors are more important (n=1).

Table 3.9. Aspects of planting sites and their advantages and disadvantages mentioned by the respondents.

Aspect	Advantages	Disadvantages	Preferred for planting
South		Nurse structure critical (n=6), High Evapotranspiration (n=6), Hot (n=3)	
West		Nurse structure critical (n=1) High evapotranspiration (n=1)	
North	Cooler temperature (n=5) Soil moisture retention (n=7) Shaded (n=2)		n=15
East	Cooler temperature (n=4) Soil moisture retention (n=5)		n=7

*Frequencies of descriptive words by respondents

To determine if certain tools had an advantage over others, respondents were asked about which tools they used or preferred. The tools used to plant seedlings are presented in Figure 3.10. Both hoedads and augers were noted for being quicker and preferred in rocky soil (n=7). It was stated that augers create a hole similar in size to a container seedling and hoedads were considered to be cheaper. The main goal was to create a hole big enough to put a seedling in without disturbing the soil or over compacting it which can be achieved by any tool (n=1).

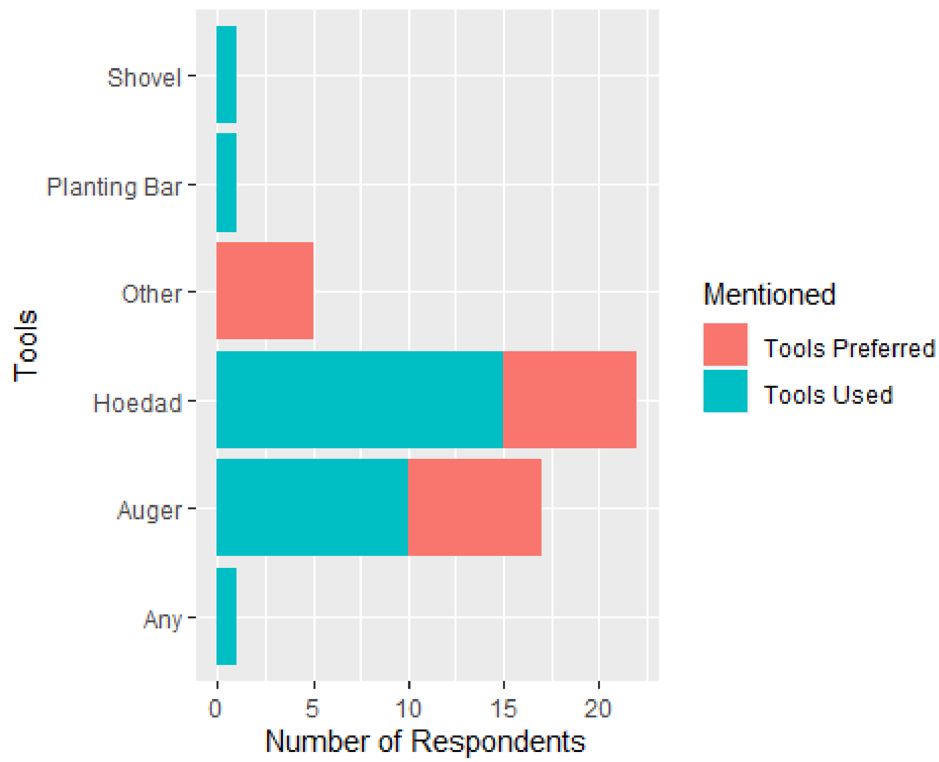

Figure 3.10. Tools used and preferred by respondents. Respondents were not limited to one response.

Most respondents recommend the use of contractors, stating that more work can be done in a smaller amount of time than other resources. While some respondents have used volunteers and employees from their organizations, they prefer contractors for bigger projects. Table 3.10 presents a summary of the responses.

Table 3.10. The pros and cons of contract planters, personnel from the same organization planting, and volunteer planters and the issues that arose and their suggested resolve mentioned by respondents.

	Planters		
	Contractors	Personnel from same organization	Volunteers
Used by Respondent	n=14	n=11	n=12
From	Local (n=11) Nonlocal (n=7)	Local (n=11)	Local (n=12)
Training provided	Yes (n=6) No (n=8)	Yes (n=9) No (n=2)	Yes (n=11)
Pros	Big Crews (n=10), Fast (n=8), Big Projects(n=6), Experienced(n=5), Lower cost (n=3), Own Inspectors (n=2), Ability to reprimand (n=2)	Personal training (n=4), Better quality (n=2), Experienced (n=2), Flexible schedules (n=2) Ties to land (n=2), Technique (n=2)	Cost (1)
Cons	Inflexible schedule (n=6), Contract process slow (n=2), Frequent inspections (n=1), Variable price (n=1), Limited contractors (n=1), Lack of experience(n=1)	Slow (n=6), Small project only (n=4), Frequent inspections (n=3), Hourly wages (n=3), Small crew (n=1), Cost more (n=1), Lack of experience(n=1)	Small projects (n=6), Slow (n=4), Lack of experience (n=1), Cannot fire for bad job (n=1), Training (1)
Issues	Going too fast (n=5), Handling of seedlings (n=3), Selective planting judgement (n=3), Planting technique (n=3), Leave seedlings in the sun (n=2), Language barrier (n=2), Lower quality (n=2), Lack inspectors (n=2), Spacing (n=1), Training (n=1), Acquisition Management shops slow (n=1), Commitment to contract (n=1), Toss trees (n=1), Hide trees (n=1)	Planting technique (n=4), Care of seedlings (n=2), Handling of seedlings (n=1)	Technique (n=2)
Resolve	Inspect often (n=6), Work alongside them (n=4), Performance based contracts (n=4), Pick contractor based on past performance (n=3), Own crew (n=2), Coordination among managers (n=1), Community involved (n=1), Require contractor inspections (n=1)	Inspect often (n=3), Training(n=2), Own crew (n=2), Verbally warning (n=2), Work alongside them (n=2)	Training (n=2)
Recommended	n=9	n=6	0

*Frequencies of descriptive words by respondents

Table 3.11 summarizes the issues with budget and budgeting process and potential ways to resolve the issues noted by the respondents. Annual budget process was stated to be the most problematic for planting projects, where contracting used by the agencies takes time. Budgets are sent in one year ahead for upcoming projects followed by applications for grants. One respondent stated that grant awarding happens when budgets are already done, noted as “backwards cycle”. One manager noted this as a reason for not applying for grants altogether. Respondents suggested that grants be awarded before budgets are turned in. Managers are often unsure if contracting will get approved until right before projects start, leaving little time to get contracts out. In some cases, optimal planting times have been missed due to this long process. Weather cycles for the following year are hard to project and managers do not know if they will have enough moisture in the following year to plant. Respondents also stated limited budget and uncertainty of funding as challenges.

Table 3.11. Issues with budgets and suggestions to resolve them by respondents.

Issues with Budgets	Reasons	Ways to Resolve
Yes (n=11)	One-year budget (n=5) Budget and grant off schedule (n=4) Proportional budgets (n=4) Contract process slow (n=3) Lack of money (n=2) Small budget (n=1) Slow process to receive donations (n=1)	Longer term budgets (n=4) Outside funding & partnerships (n=4) Multi-year agreements (n=2) Change budget and grant schedule (n=2) Reallocation of funds (n=1)
No (n=8)	Collaborative partners (n=4) Long-term budgets (n=3)	

*Frequencies of descriptive words by respondents

All respondents stated that allowing longer terms for budgets, contracts, and agreements, as well as adjusting grant deadlines and developing partnerships could increase success of planting projects. One respondent from an agency with flexible budget period stated that flexibility in budgeting has allowed for selection of optimal planting times. To deal with limited budget, respondents suggest diversifying funding sources through partnerships with private and public organizations. Respondents stated that these changes could improve the rate of success significantly.

Chapter 4 Discussion

While many factors play a vital role to artificial regeneration, site conditions are the single most important factor which cannot be changed. However, the factors discussed by the survey respondents can be altered to fit this fixed environment. For example, seed selection, nursery treatments, seedling age and height, container size, site preparation methods, spatial planting design, tree shelters, nurse structures, density of planting, season of planting, time after a wildfire, tools used, planters, and budgets all can improve the results of planting projects.

Climate change is viewed as negatively affecting planted seedlings and has influenced some respondents to select higher elevation sites due to poor survival at lower, warmer elevations. Higher temperatures and higher water stress presented by post fire conditions alter microclimate conditions critical for regeneration in ways that enhance and exacerbate drought conditions (Savage et al. 2013). Feddema et al. (2013) suggest that future scenarios of climate warming and high-severity fires all but eliminates ponderosa pine regeneration, making site selection more critical.

Site condition is the foundation for reforestation success in the Southwest. The results suggest that aspect of planting site plays a crucial role for survival of young, planted seedlings. North and east facing aspects have been observed by respondents to increase seeding survival. Sites with north and east aspects are typically cooler and have greater soil moisture in comparison to those with south and west facing aspects. Sites with north-facing aspects tend to get very little direct sunlight while those with east facing aspect are exposed at a cooler time of day minimizing evaporation of soil moisture. One study on natural regenerations of ponderosa pine after six fires in Colorado indicated that there was a positive relationship between northerly aspects and post-fire ponderosa pine regeneration (Rother and Veblen 2016). Although increased survival of seedlings has been observed on north aspects, respondents stated that sites with south aspect still require reforestation. Non-living nurse structures to create a microclimate, such as logs, shrubs, tree boles, and rocks, can be used on sites with south facing aspect as a way to ameliorate the harsher conditions. Both published studies and observations by respondents suggest that nurse structures have increased survival by providing extra moisture and protection from the sun and wind (Sánchez Meador and Moore 2010; Castro et al. 2011; Haffey et al. 2018; Owen et al. 2020). The proper placement of seedlings near nurse structures was emphasized by respondents. However, nurse structures are not always available. Tree shelters have also been used to try and create microclimates as a form of protection from sun, wind, and browse while providing extra moisture. Use of nurse structures and litter cover such as mulch, can provide extra moisture along with protection from sun and wind when available, especially on the sites with south-facing aspect.

Current site conditions need to be understood before seeds are selected and sown at the nursery. Once sites are selected and environmental conditions are understood, seeds can be selected from origins with similar environmental conditions to the project site. One study showed how budburst had differed by provenances and elevations even when planted together at the same site suggesting genetics plays a major role in growth (Dixit 2020). In the best business as usual scenario, seeds are collected from the same area with similar climate and elevation as the site (Heidmann 2008). Elevational band and latitude were used by the respondents to categorize seeds to match these conditions.

Assisted migration was suggested as an approach to increase survival of planted seedlings on sites that have now become warmer and drier. Martinez-Berdeja et al. (2019) found that seedlings with origins from lower elevation had greater relative height than higher elevational seedlings when planted together. Recommendations of using local sources are likely outdated due to maladaptation created by changing climate. This was also suggested in other studies where climate is no longer suitable for regeneration because sites had already crossed the climatic threshold for regeneration (Davis et al. 2019; Kemp et al. 2019). More research is needed to match seeds adapted to climatic conditions of the source site to planting sites under changing climate and to create flexibility in guidelines for selecting seed sources.

Although respondents understand importance of seed sources, lack of infrastructure for seed storage often limits seed availability for planting projects, making it harder to select seeds that more closely matches to the site conditions. They agree that more funding is needed to monitor and collect cones regularly. With the increase in high severity fires, the demand for seeds will only increase. The collection of seeds is crucial to success of artificial regeneration both now and in the future.

Treatments that expose seedlings in early growth stages to natural environment can be used to further prepare seedlings for warmer drier conditions. Ponderosa pine seedlings can endure severe moisture stress, appearing to shut down physiologically and recovering when moisture is available. Seedlings grown in a water stress environment had a low transpiration rates, stomatal conductance, and photosynthesis rate (Heidmann 2008). These changes in seedlings allows for decrease water loss on dry sites until moisture is available. Other treatments such as hardening off have been effective in the past, which in combination with drought treatment has the potential for increasing seeding survival.

More studies are needed to determine proper age for seedlings used in outplanting. In many studies on natural regeneration, younger seedlings had a higher mortality rate even in sites with overstory cover. The majority of mortality was attributed to desiccation (Kolb et al. 2020) and frost heaving (Heidmann 2008). Seedlings larger in size, which translate to older and taller seedlings, were less susceptible to heaving (Heidmann 2008). However, the respondents interviewed for this study observed better rate of survival for shorter stockier one-year seedlings. This age class has been observed with the highest mortality in natural regeneration literature (Kolb et al. 2020; Minott and Kolb 2020). They noted root to shoot ratios are more important than height and age. When more root than shoot is achieved, more water can be drawn than what is lost through evapotranspiration from the needles. Many respondents noted that they have not used older seedlings for planting due to added costs and difficulties of planting larger container seedlings. However, if older seedlings increase the rate of seeding survival, the benefits may outweigh the costs.

Respondents noted that containerized seedlings have increased success in comparison to bareroot in field observations and they selected size of the containers based on site conditions. Similarly, Pinto et al. (2011) suggest that is crucial to choose appropriate container size based on soil type and site conditions, especially in warmer, drier sites.

Planting season in the Southwest has moved away from traditional spring plantings to the late-summer monsoon season or the fall. In spring plantings, seedlings are subject to low or no precipitation, strong winds, low humidity, and warmer days until monsoon. Under these conditions, seedlings desiccate very quickly (Heidmann 2008). Monsoon planting which is linked to soil moisture has had better survival compared to spring planting. It is during this time that natural regenerating seedlings germinate. Ample precipitation is important in this short window for root development of young seedlings to make them less susceptible to frost heaving in the fall (Schubert 1974; Heidmann 2008). However, respondents stated that monsoon events are becoming more irregular and have not come in some years. Due to irregularities of monsoon events or drought years, some respondents have begun planting in the fall. Fall planting season has lower temperatures, evaporation rates, and evapotranspiration rates. Dormancy of seedlings results in low evapotranspiration rates. The strongest correlation with natural regeneration success was reported during the wettest conditions in the fall (Feddema et al. 2013). More studies are needed to guide appropriate planting times for artificial regeneration of ponderosa pine seedlings. All studies on natural regeneration and germination time may differ for planted seedlings that are usually one year or older stocks. Seedlings that have gone through treatments at the nursery may not be as susceptible to frost heaving or may tolerate more drought stress during years without regular monsoon events.

Planting designs are moving away from the gridded design or "pines in lines" approach and mimic both temporal and spatial variations in the natural recovery of ponderosa pine forest postfire. Ecological recovery now and in the future will have variations in densities and age due to temporal delays in natural regeneration across the landscape due to abiotic and biotic factors (Korb et al. 2019). Historical fires promoted heterogeneous conditions with generally open stands mixed with small non-forested areas (Fulé et al. 1997). Nucleation planting, also known as groupy clumpy or irregular gridded designs, are now being used to mimic historical forest structure. Areas that have a greater potential for survival or were once stocked with higher densities of ponderosa pine are selected for planting, leaving less suitable site such as rocky soils unplanted. This approach was suggested in another study, which selects topoclimatic refugia for increased survival even in less suitable sites (Korb et al. 2019) which can also decrease fire hazards (North et al. 2019).

Following wildfire, natural regeneration has the greatest potential for success near seed sources (Haffey et al. 2018). Areas outside of the natural seed dispersal range require artificial regeneration of seedlings for rapid reforestation. A study employed repeated measurements of tree age following wildfires showed that rate of regeneration increases over time as trees in general continue to establish after each germination event (Davis et al. 2019). This process is slow due to harsh conditions. One repeated study observed negligible natural regeneration over a 15-year period, suggesting that factors other than seed dispersal affect regeneration (Stoddard et al. 2018). More studies are needed to determine appropriate times for planting following wildfires because natural regeneration has showed mixed results. Some respondents noted that planting should occur soon after a wildfire when sites are still bare and competition with other vegetation is low, requiring minimal site prep and capturing nutrients that can be washed off. However, others noted some advantages of later planting including facilitation by other vegetation, soil recovery, and natural regeneration.

Managers have some understanding of what factors increase success through field observations but have little flexibility with short term budgets. While abiotic conditions of sites are fixed, all other adjustments, such as seed collection, planting crews, and planting times, require long term planning. Ponderosa pines do not produce a cone crop every year which is problematic with one-year budgets, making it hard to collect cones when they are ready from locations that more closely matches the site. This also limits the availability of seeds. Longer term budgets could also allow for more flexibility in scheduling of contractors and planting time. Planting time linked with moisture events are hard to project one year out and have become irregular. Waiting for the years with ample moisture will increase survival overall and create flexibility in scheduling of crews. This can also be seen in natural regeneration in that germinations only happen in years with high precipitation (Feddema et al. 2013). Longer term budgets will promote artificial regeneration by creating flexibility in planting projects, allowing managers to plant when the site conditions are suitable for establishment of artificial ponderosa pine regeneration.

Chapter 5 Conclusions and Management Implications

Planting experts in the Southwest were in consensus about several key elements of the artificial regeneration process, specifically aspect of planting sites, genetic importance of seed sources, effectiveness of nurse structures, treatments, use of containers, and planting design. However, there were other elements where experts had differing experiences and opinions, notably level of genetic adaptation of seeds, optimal planting season, effects of site preparations, and use of tree shelters. The areas of divergent views indicate a need for more research to address questions related to ponderosa pine planting. While there is a growing body of literature that discusses natural regeneration, research specific to artificial regeneration is needed, especially in the areas where observations made by the experts do not correlate with the literature about natural regeneration. Specific areas for future research include effectiveness of tree shelters, effects of site aspect, seedling age and height, fall or monsoon planting seasons, and site preparation. While some results of this study have implications for future research, others are directly relevant to management. Reforestation experts in the Southwest consistently emphasize the needs for more funding and seed collection programs and short-term budgets as an important challenge that should be addressed in the near term. Artificial regeneration is a critical tool for addressing the challenges of severe disturbance and warming climate. Expert opinions contribute valuable knowledge for sustaining forest ecosystems in the Southwest.

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