Southern Nevada: Ponderosa Pine Regeneration Research Summary

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Photo of sampling at site NVSP-BCPP-1 in 2019

Photo of sampling at site NVSP-DLPP-1in 2019

Overview

In 2019 and 2021, we characterized 77 ponderosa pine sites across 7 regional locations in the southwestern United States. This included 14 sites in southern Nevada, sampled in 2019 and 2021 at the Humboldt-Toiyabe National Forest (HTNF), as well as an additional ponderosa pine site sampled in 2019 at the Desert National Wildlife Refuge. Our primary focus was to better understand natural regeneration in undisturbed or lightly disturbed forest environments.

In 2019, we characterized forest attributes, regeneration density, and we excavated a large number of ponderosa pine seedlings (< 0.5 m height) to learn more about their above- and belowground growth at early stages of development. In 2021, our focus was to characterize forest attributes and regeneration density across unmanaged and managed forests. Management varied among locations, and included basal area thinning, understory thinning, and understory burning.

Following this sampling, we parameterized sites in a computational water balance model, and simulated the temperature and moisture characteristics of each site over historical time periods (1980-2020). This allowed for follow up research exploring the meteorological, moisture, and temperature conditions associated with regeneration at each sampling site and each study location.

In a separate research project initiated in 2022, we are conducting an experimental study focused on quantifying the survival and mortality of planted ponderosa pine seedlings at HTNF. An overview of this ongoing work and our objectives are summarized in this report.

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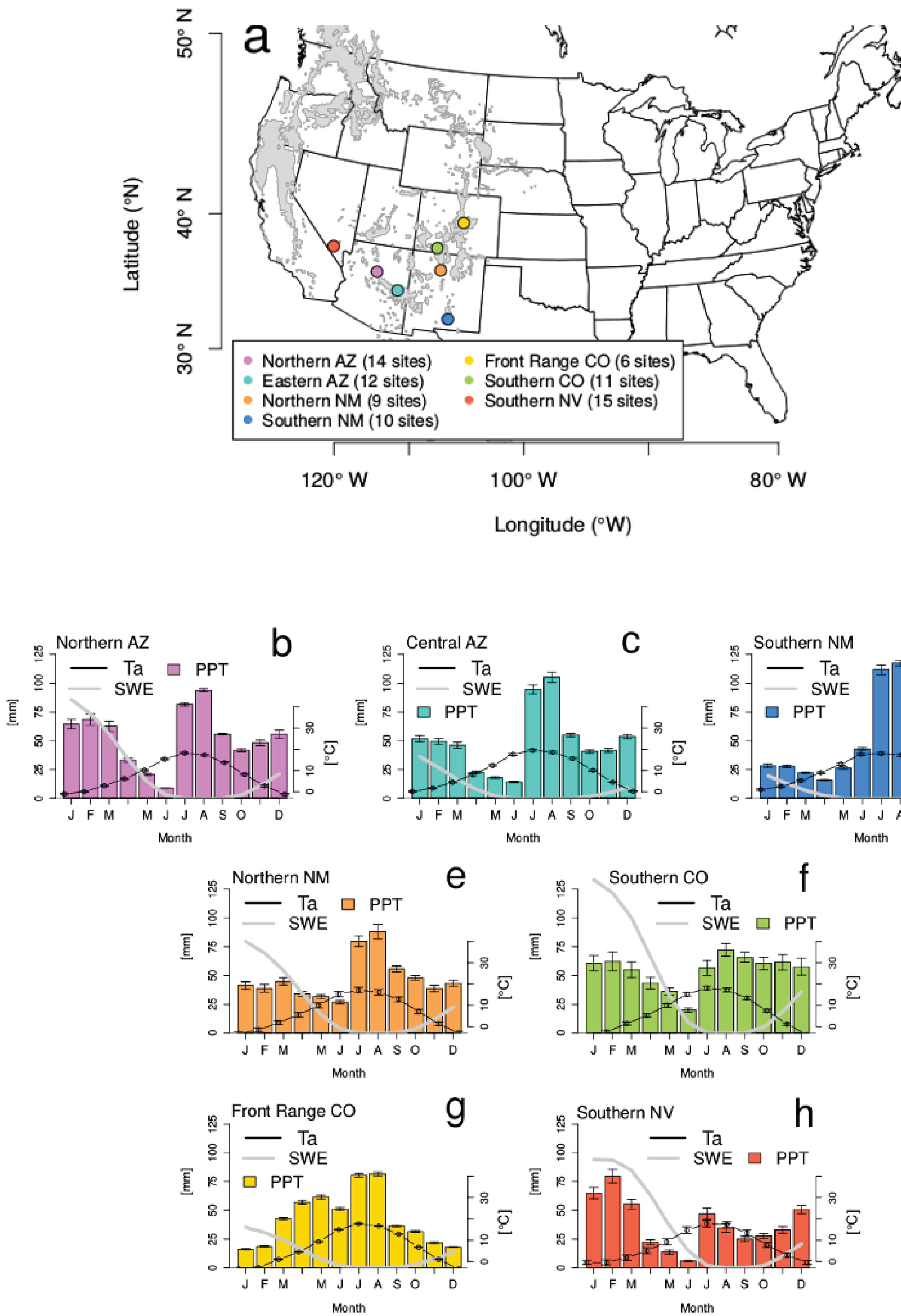
Figure 1: Map of 2019 and 2021 research locations and number of sites characterized at each location (Panel a), and climate diagrams illustrating average monthly precipitation [PPT: mm], snow water equivalent [SWE: mm], and daily mean air temperature [ºC] for research locations (Panels b-h). PPT and Ta values were derived from daily DayMet estimates (1980-2020), and SWE was estimated using the SOILWAT2 model from DayMet forcing. The error bars illustrate variation across study sites in each location.



Site	Latitude [ºN]	Longitude [ºW]	Management	Elevation [m]	Basal Area [m^2 ha^{-1}]	Ponderosa Seedlings [# m^2]	Canopy Cover [%]	Cones [# m^2]	Herb Cover [%]	Shrub Cover [%]	CW Debris [%]	Litter Cover [%]
NVSP-WWPP-1	36.3328	115.664	N	2536	28	0.000	28.0	2.5	2.6	36.9	3.1	48.1
NVSP-BCPP-1	36.3172	115.6797	T	2611	24	0.005	24.0	10.4	6.5	10.4	3.0	78.4
NVSP-DLPP-1	36.3331	115.6510	N	2516	20	0.003	20.0	2.1	7.4	0.4	1.1	64.4
NVSP-BCPP-4	36.3179	115.6814	N	2601	20	0.011	20.0	3.1	3.9	13.6	8.6	70.6
NVSP-BCPP-5	36.3093	115.6877	T	2680	20	0.006	20.0	3.9	9.9	1.5	0.3	65.6
NVHT-U1	36.3282	115.6593	N	2515	16	0.000	23.4	0.4	5.1	9.4	40.6	40.0
NVHT-U2	36.2595	115.6234	N	2252	16	0.547	36.9	5.6	19.4	0.0	23.8	66.9
NVHT-M1	36.3327	115.6649	T	2534	14	0.000	34.3	2.0	0.0	10.0	21.3	81.3
NVHT-M2	36.3316	115.6654	T	2509	40	0.000	54.6	2.6	0.0	0.0	13.8	93.1
NVHT-M3	36.3277	115.6599	T	2497	16	0.005	36.1	1.1	15.0	0.0	71.3	56.3
NVHT-M4	36.3033	115.6753	T	2612	34	0.013	53.6	4.5	3.4	11.3	24.4	93.8
NVHT-M5	36.3036	115.6747	T	2662	22	0.022	42.1	0.5	2.4	0.0	39.4	83.8
NVHT-M6	36.26	115.6234	T	2235	16	0.025	29.9	2.8	34.4	0.0	29.4	74.4
NVHT-M7	36.2599	115.6243	T	2179	16	0.038	55.1	2.0	6.5	18.1	10.6	90.6

Table 1: Latitude, longitude, management, elevation, basal area, seedling density, canopy cover, cone density, herb cover, shrub cover, CW debris, and litter cover of 14 different sampling sites of ponderosa pine trees in southern NV.
Note: N = no management; T = overstory thinning. To estimate seedling density in # ha^{-1}, multiply # m^{-2} by 10,000.

Seedling Growth Characteristics

Ponderosa pines spend an extended period of time at the seedling stage—as many as 15+ years less than 0.5 m in height. During early stages of growth, they first allocate growth belowground, and once their main taproot is 30-40 cm deep (just past the soil evaporation zone), they begin to partition more of their growth aboveground. They do not appear to adjust their above- and belowground growth in different environments (more or less shaded, drier or wetter, etc.).

In warmer and drier forest sites, a greater proportion of seedlings are located in sheltered microclimates. In a warming environment, these sheltered microclimates will be important for regeneration success, especially since seedlings are unlikely to adjust their growth in response to a warming environment.

Regeneration Failure

We found that nearly one-third (29%) of the 77 ponderosa pine sites we characterized had experienced no regeneration over the past ~20 years. In southern NV, 5 sites had experienced regeneration failure (33% of sites), which was a higher than average rate of regeneration failure for the 7 locations where we conducted our research. We were able to attribute regeneration failure across the SWUS to specific meteorological conditions, most notably seasonal heat loading (warmer than average temperatures), loss of cool-season (winter) climate characteristics, and soil moisture variability. In our analyses, some explanatory conditions promoted regeneration failure, whereas others inhibited regeneration failure. Winter climate in southern Nevada is cool with relatively high snowfall, and is comparable to favorable SWUS locations such as northern AZ. In contrast to other SWUS locations, the summer climate of southern Nevada exhibits higher than average heat loading and water balance variation, promoting regeneration failure. Natural regeneration failure is occurring throughout the SWUS, and is notably high in southern Nevada.

In contrast to regeneration failure, 1 site we sampled at HTNF had exceedingly high regeneration densities (> 0.1 seedlings m^{-2}; 1,000 seedlings ha^{-1}). This was the only unmanaged ponderosa pine site with exceedingly high regeneration in the entire SWUS. These trees germinated in summer 2021 (see photo), and it is unclear if they have survived. Regardless, their presence illustrates the potential for natural regeneration in southern NV.

Photo of recently germinated seedlings at site NVHT-U2 in 2021

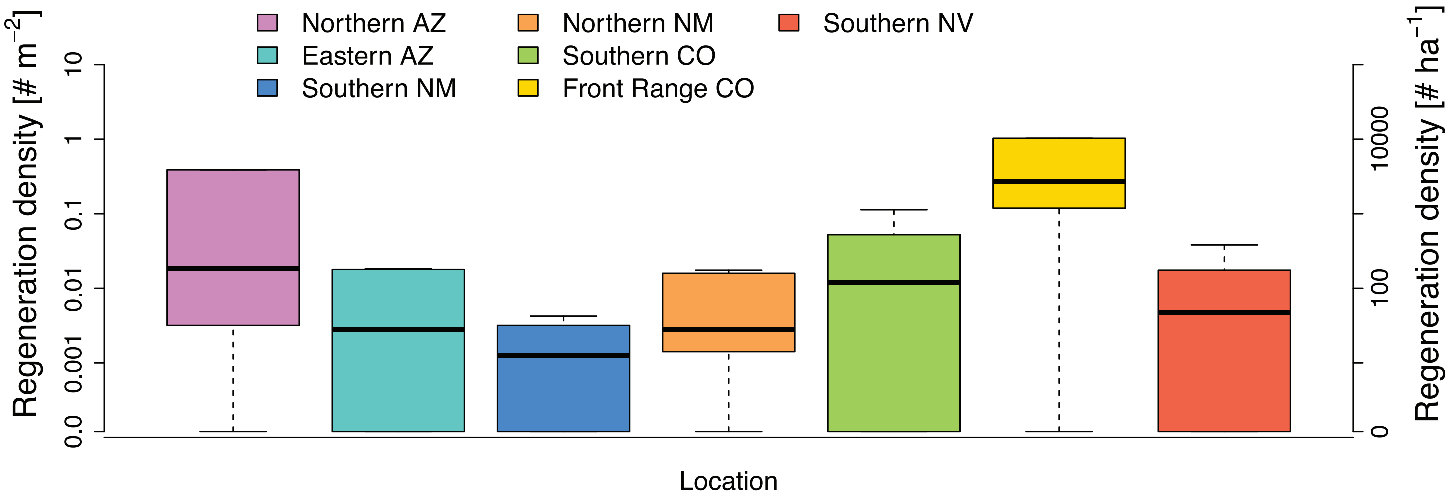


Figure 2: Boxplots illustrating variation in juvenile ponderosa pine regeneration density [# seedlings m^{-2}, # seedlings ha^{-1}] between sites in differing regional locations. Due to wide variation in regeneration density and many sites with no regeneration, we found no significant differences in regeneration density between study locations (ANOVA and Tukey's honest significant differences; $p < 0.05$).

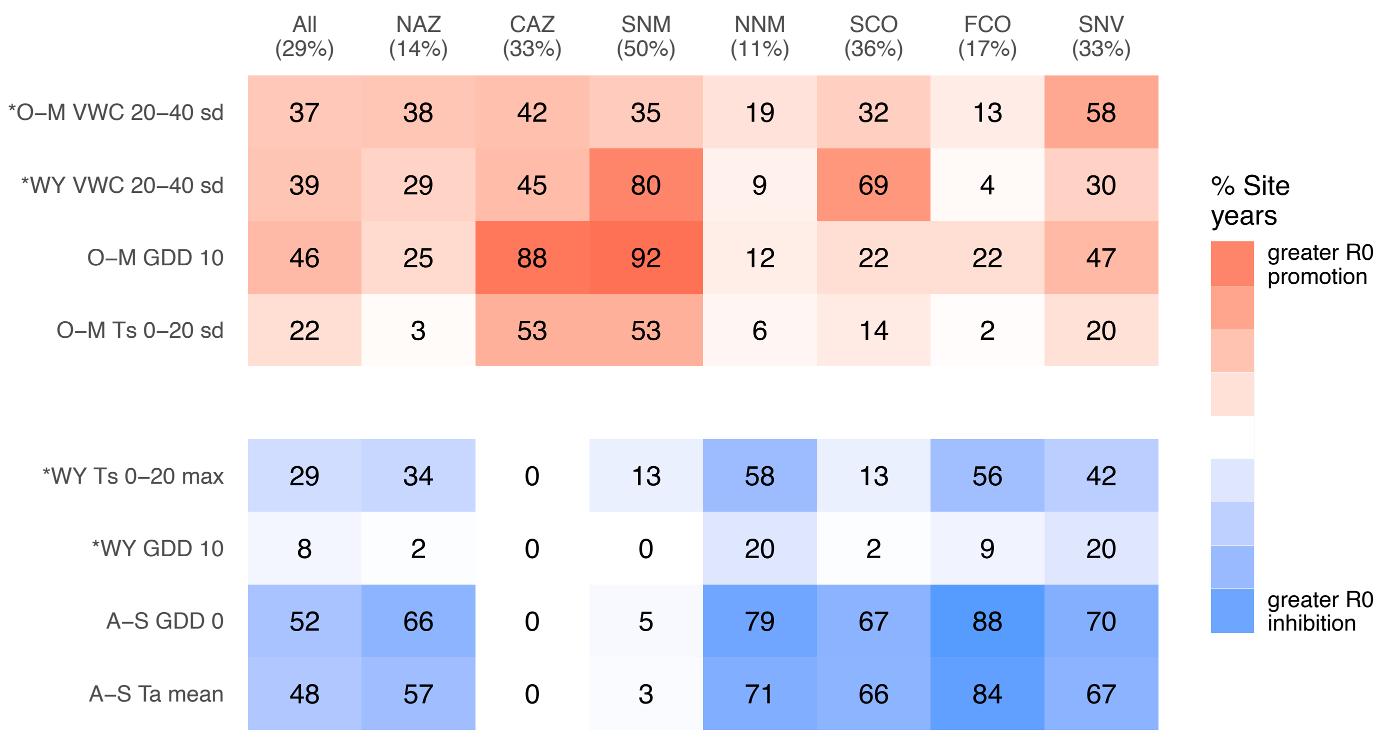


Figure 3: Evaluation of explanatory meteorological and water balance variables associated with greater promotion or greater inhibition of regeneration failure [R0: 0.0 seedlings m^{-2}] for all study sites (All), and for sites within different locations of the southwestern US. Top variables are indicated by a star (*). In each box, the value and color indicate the percentage of years/seasons for 20 years prior to the sampling date (2019 sampling: 1999-2018; 2021 sampling: 2001-2020) exceeding the boundary value of each variable. These boundary values were used to differentiate R0 sites from those experiencing regeneration using partial dependence from a random forests analysis. The percentage values below each location indicate the percentage of sites at that location experiencing regeneration failure.

Management Effects On Regeneration

Managed ponderosa pine forest sites generally had higher natural regeneration than unmanaged ones, and sites experiencing thinning and understory burning generally had higher regeneration than other managed sites. Based on our estimates of seedling age at each site, the majority of regeneration occurred ~10 years after management occurred. Very few managed sites experienced regeneration failure.

It is difficult to broadly attribute management actions to regeneration success because climates differ across the SWUS, management activities differ across USFS districts, and environmental change in post-management forests is complex and not limited to just moisture and temperature. SWUS locations where many management activities are developed (northern Arizona, Colorado Front Range) may not be the optimum management for other locations. In the context of regional climate change, it appears that management activities will need to be developed for specific locations and forest settings.

We evaluated the success of management activities at each location in promoting regeneration as an effect ratio (how much higher or lower regeneration was in managed compared to unmanaged forest sites). Southern NV had an effect ratio < 1.0, suggesting that, on average, current management activities are not successful at promoting regeneration. Management outcomes may improve in southern NV with a lessening of dry regional conditions—it may also be worthwhile to experiment with sheltered microsites and understory burning to promote regeneration success. Moving forward, it will be important to consider the role of climate in shaping regeneration outcomes—management that has been successful under current conditions may need to be adjusted in the future as climate change progresses. It may be advantageous to design management that targets specific climate conditions (wet years, average conditions, etc.).

Part a. Study locations

Location	No Regeneration [%]	Managed [%]	Thinning [%]	Thinning + Burning [%]
Northern AZ	14.3	78.6	0.0	78.6
Central AZ	33.3	83.3	25.0	58.3
Southern NM	50.0	60.0	60.0	0.0
Northern NM	11.1	66.7	55.6	11.1
Southern CO	33.3	81.8	27.2	54.6
Front Range CO	16.7	100.0	83.3	16.7
Southern NV	33.3	60.0	60.0	0.0

Part b. Regeneration densities

Regeneration Density	Managed [%]	Thinning [%]	Thinning + Burning [%]
R0 [0 m^{-2}]	63.6	40.9	22.7
R1 [0-0.01 m^{-2}]	65.0	45.0	20.0
R2 [0.01-0.1 m^{-2}]	81.8	31.8	50.0
R3 [0.1+ m^{-2}]	92.3	46.2	46.2

Table 2: Summary of regeneration attributes and management actions for sampling locations (Part a), and for regeneration density classifications (Part b).

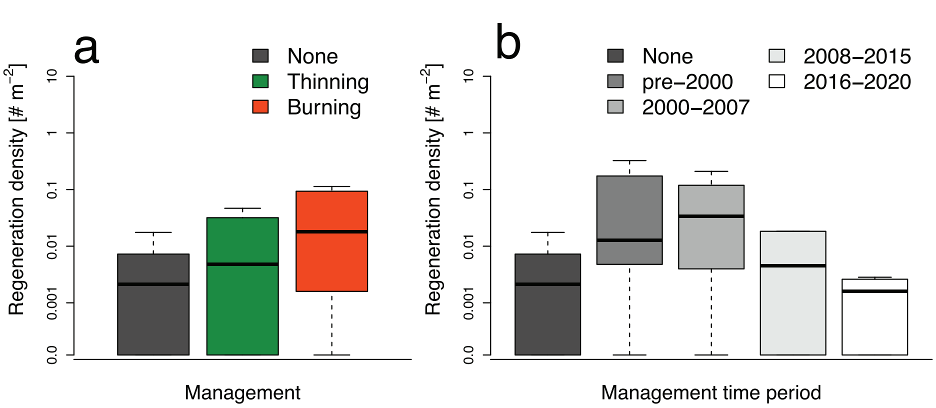


Figure 4: Boxplots of regeneration density between unmanaged, thinned, and burned sites (Panel a), and regeneration density between unmanaged sites and sites with differing time periods of past management (Panel b). Due to wide variation in regeneration density and many sites with no regeneration, we found no significant differences in regeneration density between management actions, or between management time periods (ANOVA and Tukey's honest significant differences; $p < 0.05$).

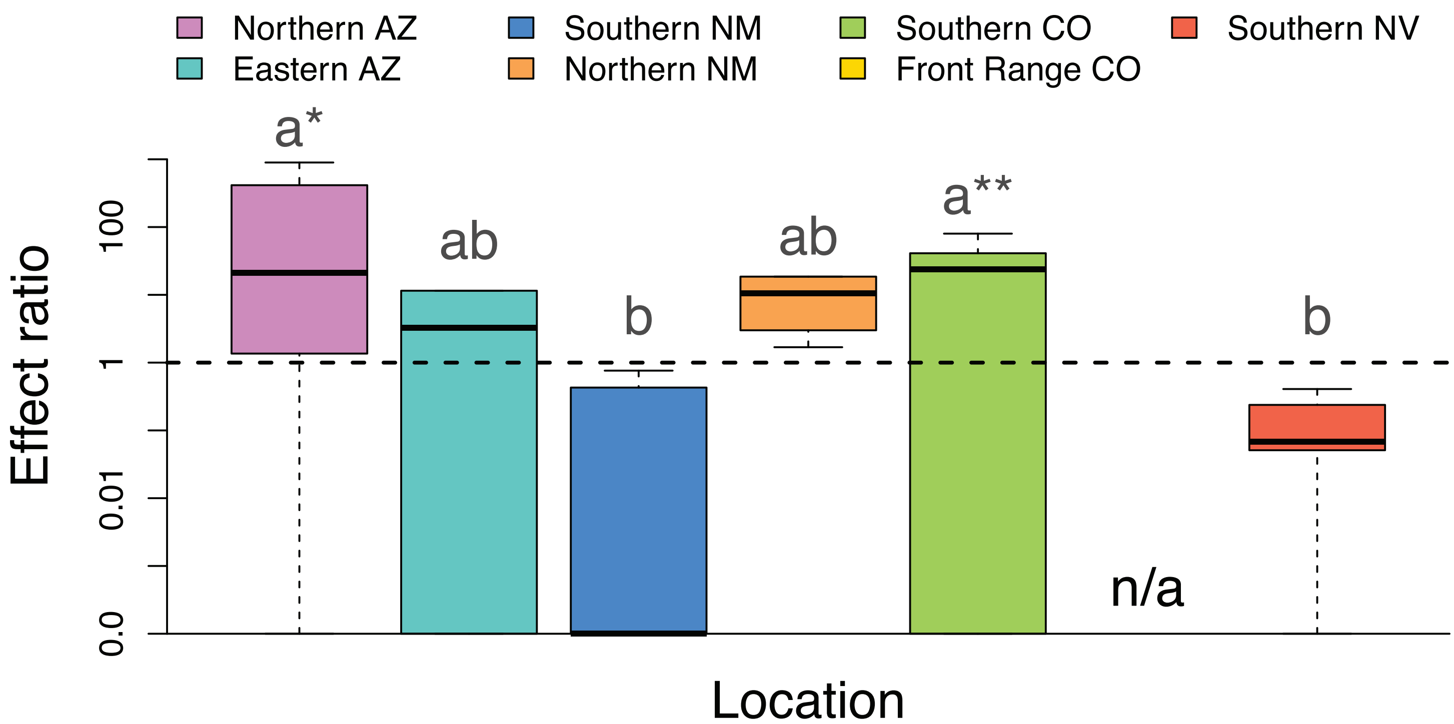


Figure 5: Boxplots comparing regeneration density between managed and unmanaged sites on a ratio scale (managed density divided by unmanaged density) in differing regional locations of the SWUS. An effect ratio > 1.0 indicates managed sites had higher regeneration than unmanaged sites. All sites in Front Range CO were managed. Significant differences were determined using ANOVA and Tukey's honest significant differences (*p < 0.05; **p < 0.01).

Juvenile Hydraulic Vulnerability

In 2021, we sampled the branches of juvenile ponderosa pines (20-30 years in age) at 6 locations in the SWUS, and analyzed their hydraulic vulnerability in the lab. We assessed hydraulic vulnerability as the p50 value of sampled branches, which is the water potential at which point 50% of the xylem are cavitated.

The p50 values of ponderosa pine juveniles in southern NV were significantly lower (greater hydraulic stress tolerance) than those in many other SWUS locations. These differences can be attributed to both low warm season precipitation and relatively shallow soils with low water holding capacity in the HTNF compared to other regions. We will need to conduct follow up research to determine if this difference is due to population adaptation, acclimation, or simply an unfavorable environment killing individuals that are less stress tolerant. We will keep you up to date on this research, and expect to have a publication completed sometime in late 2023.

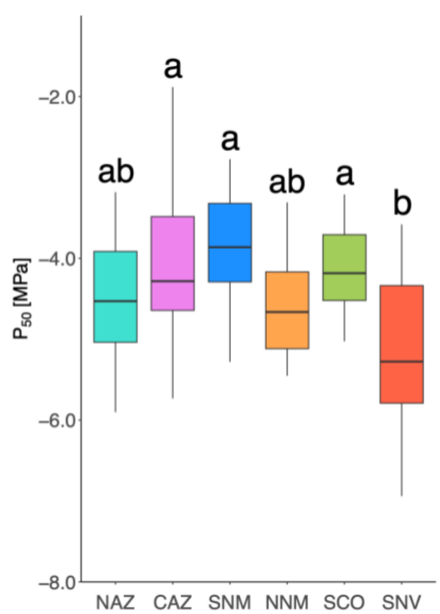


Figure 6: Boxplots illustrating the average p50 value [MPa] of juvenile ponderosa pines (20-30 years in age) between study locations. The p50 value indicates the pressure at which 50% of a ponderosa pine's conduits (xylem) cavitate, and a more negative p50 value indicates greater physiological tolerance of moisture stress. Panel a shows that ponderosa pine juveniles in southern NV are more stress tolerant than juveniles in other locations. Determining why this occurs may help to uncover new management opportunities for human-assisted reforestation.

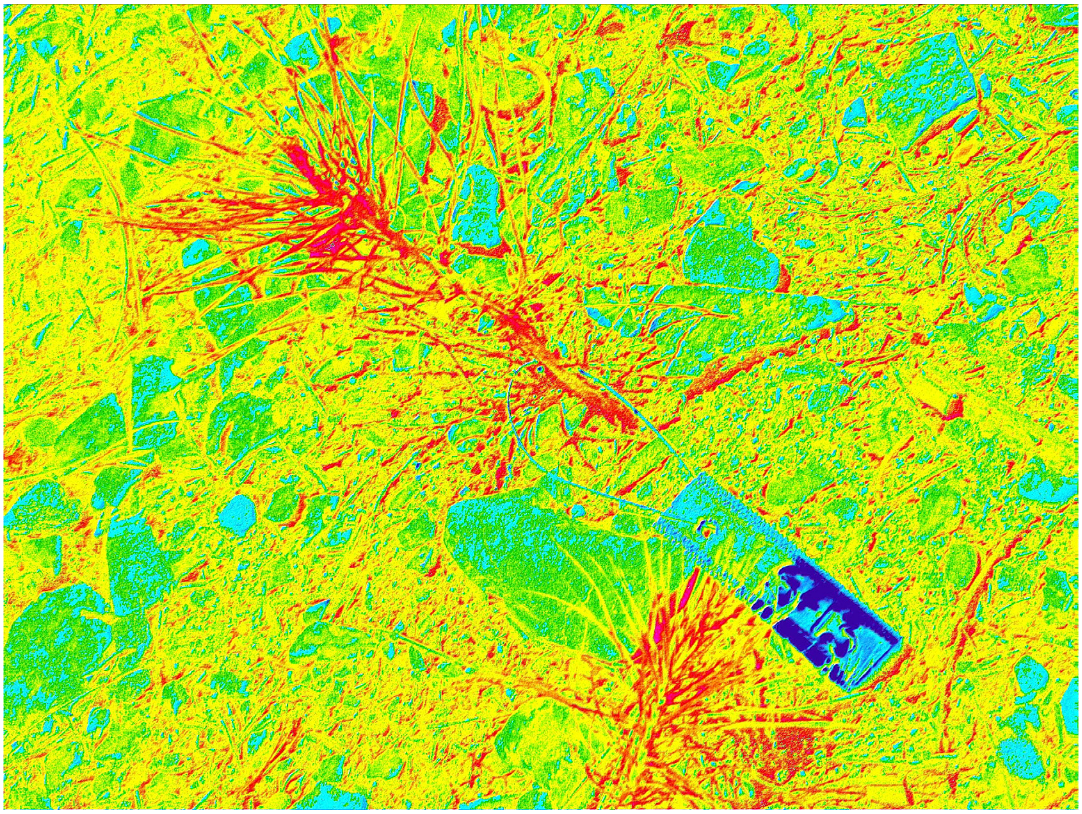
Photo of instrumentation used to monitor planted seedling survival at HTNF. This site is in Wallace canyon, near the old USFS HOBO weather station.

Planted Seedling Monitoring

In 2022, we initiated a planted ponderosa pine seedling monitoring study in the HTNF. Tree planting occurred at 4 locations where we previously installed meteorological and environmental instrumentation, as well as ground based remote sensing instruments that we tested for their ability to detect seedling stress and mortality. In the first year, we planted trees among 3 treatments—(A) control trees planted using local USFS protocols in late April; (B) trees rejuvenated in the greenhouse and planted ~15 days later; and (C) trees rejuvenated in the greenhouse and planted ~15 days later with a soil hydrogel amendment.

Seedling survival was very low across all treatments, which is expected given low warm season precipitation in southern NV. Survival was highest in Group A, trees planted immediately following shipment. Although we're still working through the data, we hypothesize that this survival may be attributed to the longer in situ acclimation period that these trees received, compared to those planted at a later date.

In 2023, we're going to continue this research at 3 HTNF locations (we lost a site to the ski area), and test the acclimation hypothesis. Can we plant trees earlier in spring, risk frost and freezing damage, and improve planting outcomes?



Normalized Difference Vegetation Index (NDVI) image of a planted ponderosa pine seedling. We are using instrumentation to detect changes to the spectral properties of planted seedlings, which may help us better identify stress onset and tree mortality. A brown seedling has already been dead for some time!

Photo of instrumentation used to monitor planted seedling survival at HTNF. This site is in Scout canyon, near the existing SNOTEL station.

Aridification in the Spring Mountains

In southern Nevada, we have performed detailed characterizations of the sites that we have sampled, and the sites where we have installed instrumentation. These sites have been parameterized into a computational ecosystem water balance model (US Geological Survey's SOILWAT2 model), and we have simulated the water and temperature dynamics of these sites from 1915-2020 using a variety of gridded climate data products. In mid-2023, we will be analyzing these simulations to assess patterns of aridification across forest and woodland ecosystems of southern Nevada, and will be providing a report to your office later in the year.

The SOILWAT2 model is also equipped to simulate climate change scenarios using a suite of 36 different General Circulation (Climate) Models. Keep this capacity in mind as you think about the future of your forest—we have the capacity and expertise to provide detailed information that is management-focused, and can help guide the important decisions your office will be making in the future.

Upcoming Work & Collaboration Opportunities

We are publishing the results of this work. We will contact your office when these studies are available.

We are also conducting studies to increase the success of tree planting efforts in both undisturbed and post-wildfire ponderosa pine forests. We are developing new mechanistic insight on why many planting efforts fail, and are developing planting strategies to combat these mechanisms. We are working to expand this research, and will keep your office informed of any progress we make. It would make sense to incorporate your insights and needs into this work, and we will be excited to discuss possibilities with you.

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Related Publications

Petrie MD, Wildeman AM, Bradford JB, Hubbard RM, and Lauenroth WK. 2016. A review of precipitation and temperature control on seedling emergence and establishment for ponderosa and lodgepole pine forest regeneration, Forest Ecology and Management 361: 328-338, doi:10.1016/j.foreco.2015.11.028.

Petrie MD, Bradford JB, Hubbard RM, Lauenroth WK, Andrews CA and Schlaepfer DR. 2017. Climate change may restrict dryland forest regeneration in the 21st century, Ecology 98: 1548-1559, doi:10.1002/ecy.1791.

Petrie MD, Bradford JB, Lauenroth WK, Schlaepfer DR, Andrews CA and Bell DM. 2020. Non-analog increases to air, surface and belowground temperature extreme events due to climate change, Climatic Change 163: 2233-2256, doi:10.1007/s10584-020-02944-7.

Pirtel NL, Bradford JB, Hubbard RM, Abella SR, Kolb TE, Litvak ME, Porter SL and Petrie MD. 2021. The aboveground and belowground growth characteristics of juvenile conifers in the southwestern United States, Ecosphere 12: e03839, doi:10.1002/ecs2.3839.

Koehn CR, Petrie MD and Hubbard RM. 2022. Not only severe events: Moderate dry periods impact the hydraulic functioning and survival of planted ponderosa pine seedlings, Forests 13: 370, doi:10.3390/f13030370.

Petrie MD, Hubbard RM, Bradford JB, Kolb TE, Moser WK, Noel A and Schlaepfer DR. Widespread regeneration failure in ponderosa pine forests of the southwestern United States, in review.

Petrie MD, Hubbard RM, Bradford JB, Kolb TE, Noel A and Schlaepfer DR. Refining perspectives on management and regeneration in ponderosa pine forests, in preparation.

Brewer TE, Petrie MD, Hubbard RM, Bradford JB, Kolb TE, and Schlaepfer DR. Hydraulic vulnerability of ponderosa pine juveniles in the southwestern US, in preparation.

Noel A, Petrie MD, Hubbard RM, Bradford JB, Kolb TE, Noel A and Schlaepfer DR. Optimum forest densities for regeneration in scenarios of future climate change, in preparation.