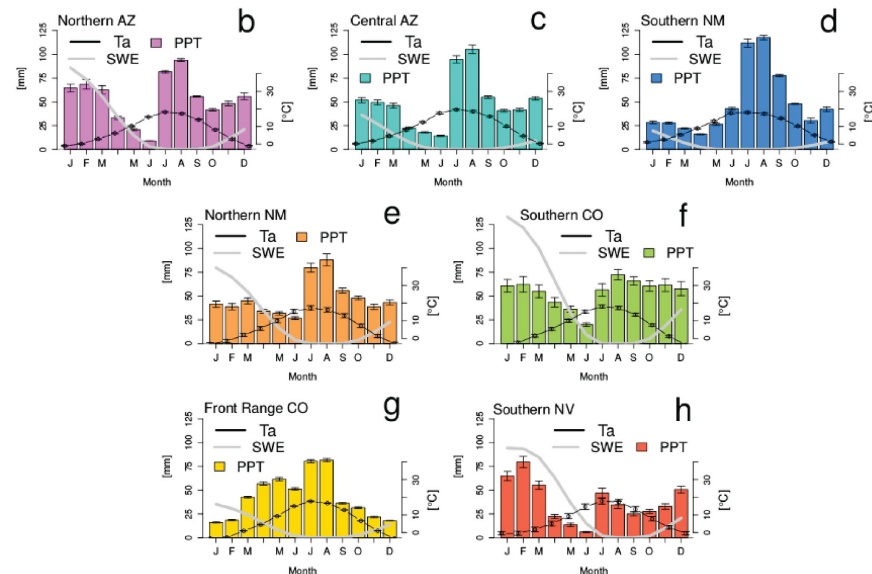
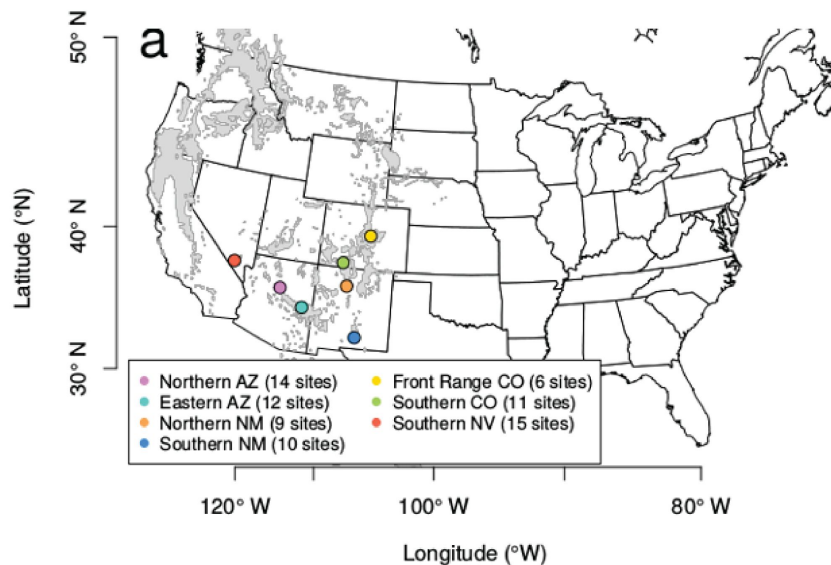


SOUTHERN NEVADA:

Ponderosa Pine Regeneration Research



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 [°C] 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 [°N]	Longitude [°W]	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

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.



Photos of samplings in
 2019 & 2021



Photos of sampling at site NVSP-WWPP-1 in 2019



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



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



Photos of sampling at site NVSP-BCPP-4 in 2019



Photos of sampling at site NVSP-BCPP-5 in 2019



Photos of sampling at site NVHT-U1 in 2021



Photo of recently germinated seedlings at site NVHT-U1 in 2021



Photos of sampling at site NVHT-U2 in 2021



Photos of sampling at site NVHT-M1 in 2021



Photos of sampling at site NVHT-M2 in 2021



Photos of sampling at site NVHT-M3 in 2021



Photos of sampling at site NVHT-M4 in 2021



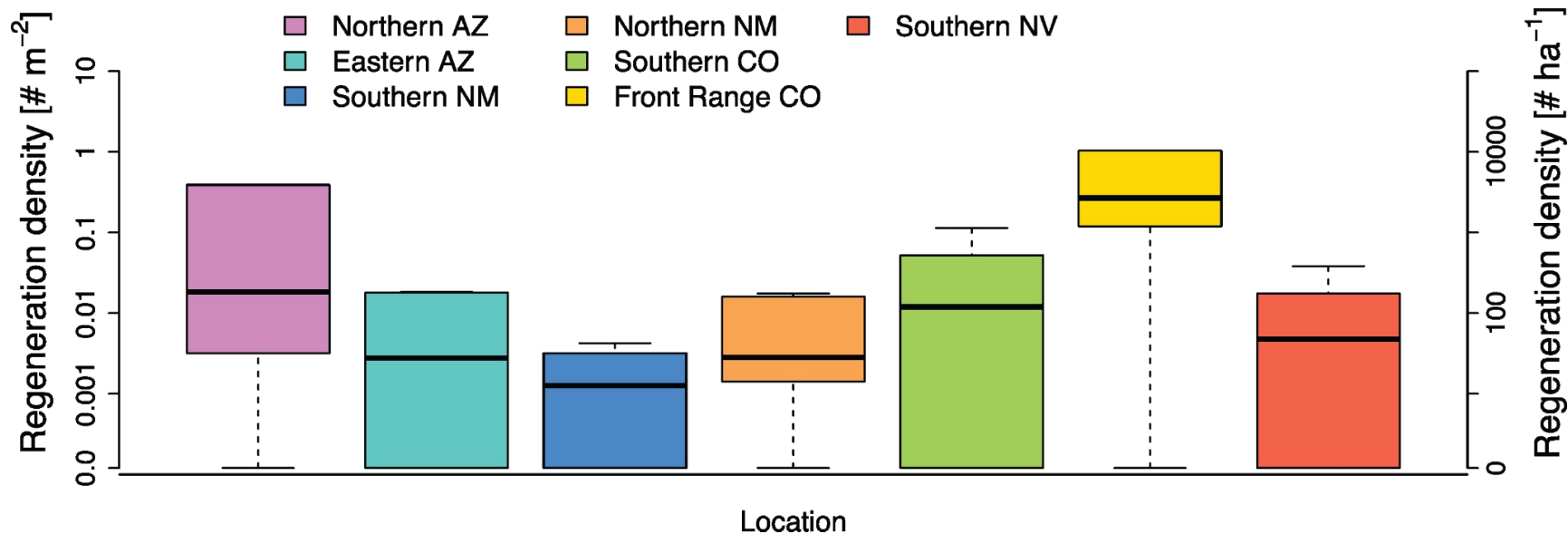
Photos of sampling at site NVHT-M5 in 2021



Photos of sampling at site NVHT-M6 in 2021



Photos of sampling at site NVHT-M7 in 2021



Boxplots illustrating variation in juvenile ponderosa pine regeneration density [$\# \text{ seedlings m}^{-2}$, $\# \text{ seedlings ha}^{-1}$] 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; $p < 0.05$).

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.

	All (29%)	NAZ (14%)	CAZ (33%)	SNM (50%)	NNM (11%)	SCO (36%)	FCO (17%)	SNV (33%)
*O-M VWC 20-40 sd	37	38	42	35	19	32	13	58
*WY VWC 20-40 sd	39	29	45	80	9	69	4	30
O-M GDD 10	46	25	88	92	12	22	22	47
O-M Ts 0-20 sd	22	3	53	53	6	14	2	20
*WY Ts 0-20 max	29	34	0	13	58	13	56	42
*WY GDD 10	8	2	0	0	20	2	9	20
A-S GDD 0	52	66	0	5	79	67	88	70
A-S Ta mean	48	57	0	3	71	66	84	67

% Site years

greater R0 promotion

greater R0 inhibition

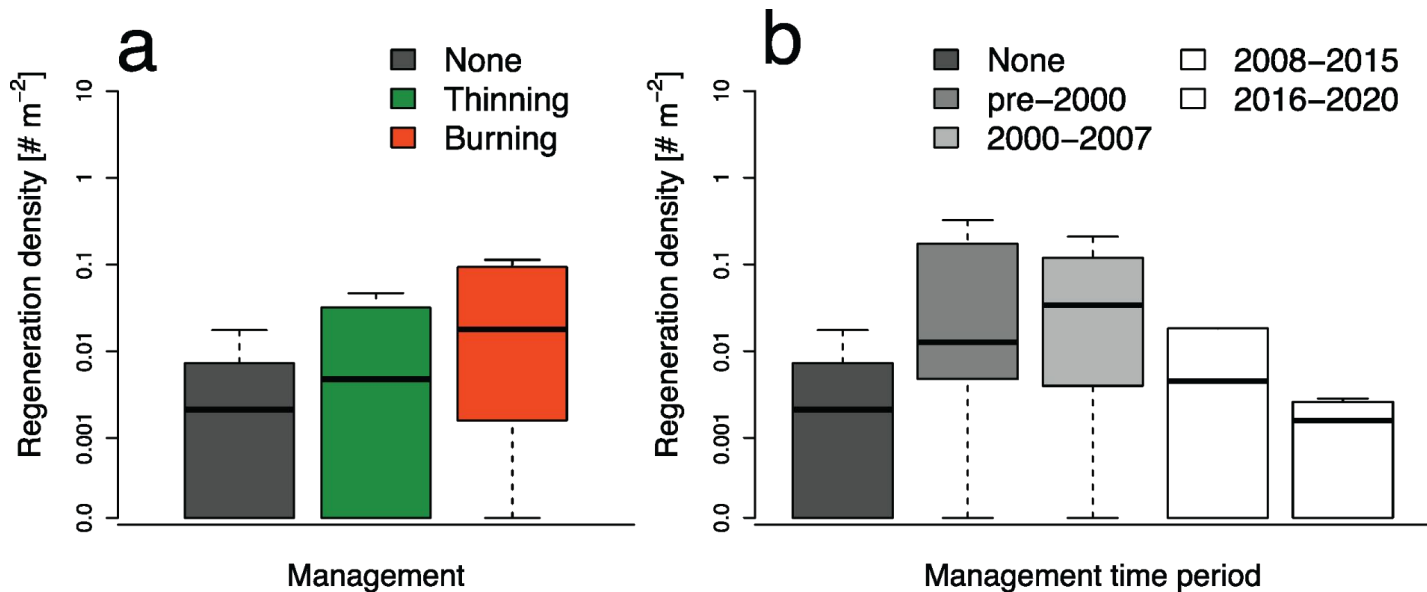
Part a. Study locations

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

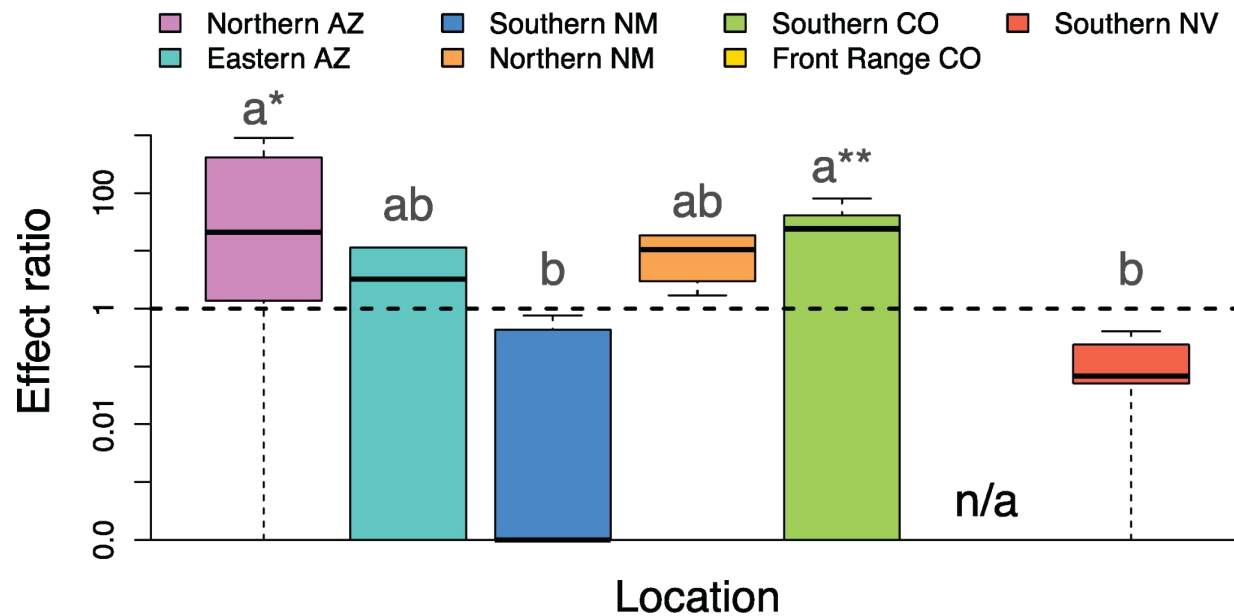
Part b. Regeneration densities

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

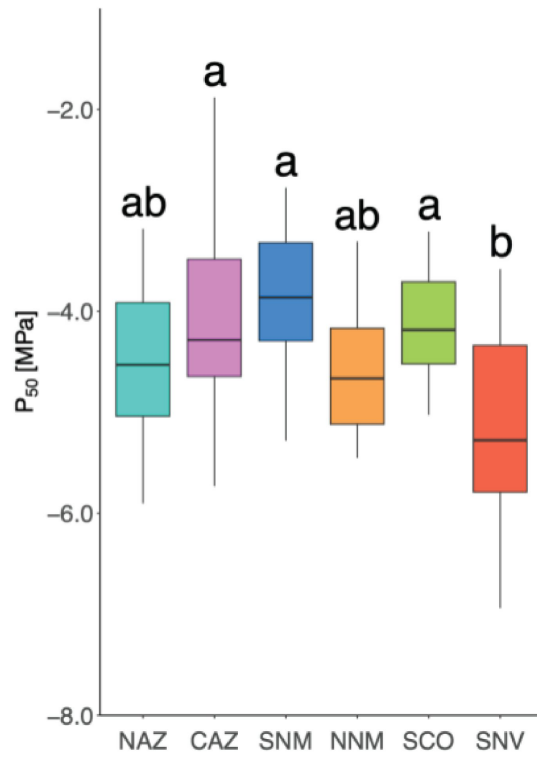
Summary of regeneration attributes and management actions for sampling locations (Part a), and for regeneration density classifications (Part b).



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; $p < 0.05$).



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 (* $p < 0.05$; ** $p < 0.01$).



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.

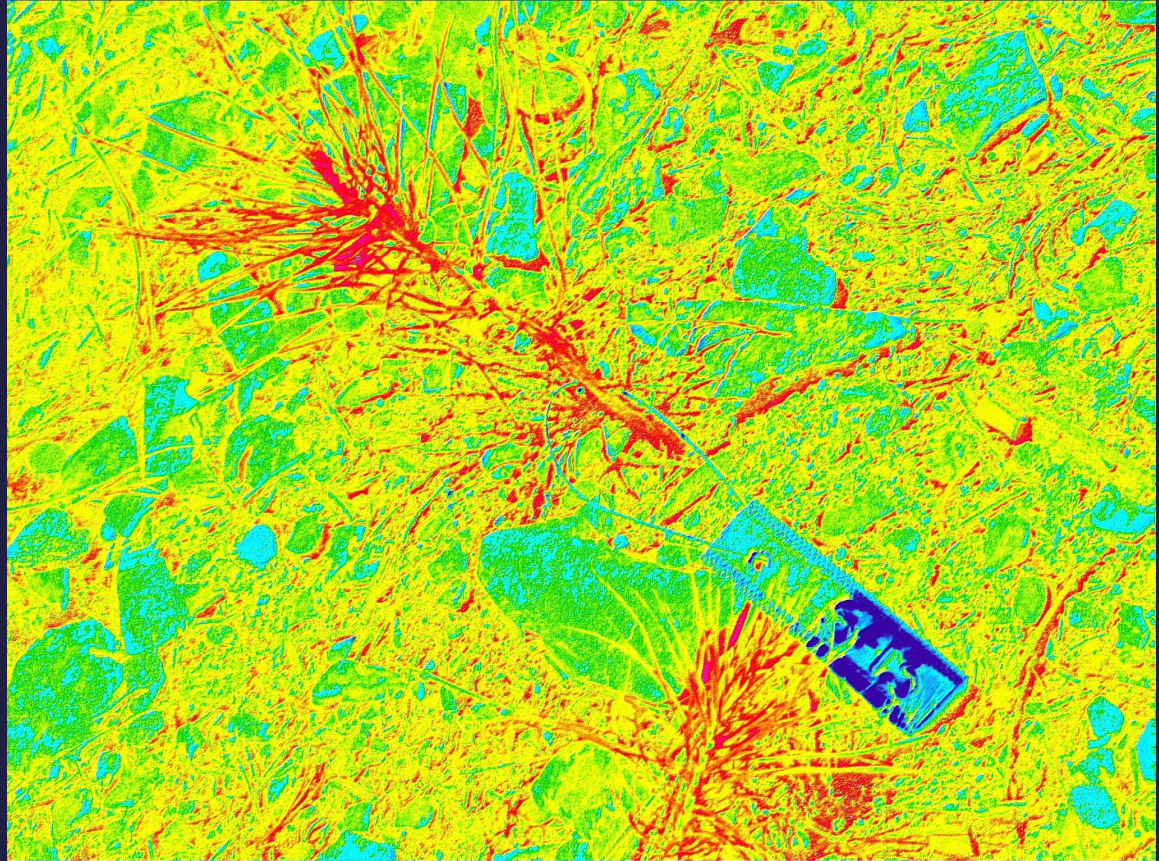


Photo of instrumentation used to monitor planted seedling survival at HTNF. This site is in Wallace canyon, near the old USFS HOBO weather station.



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

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!





Southwest
Climate Adaptation
Science Center



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SCIENCES

Designed by Kaesee Bourne
UNLV Student Communications Technician

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.