

Compositional legacies of fire suppression maintained after fire re-entry

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Appendix 1

Preliminary Analyses

Linear Regression

We performed a series of preliminary linear regression analyses to examine relationships between seedling abundance, topography, forest structure, and shrub parameters. We included Transect ID as a random effect to account for spatial autocorrelation between quadrats. For seedling abundances, a negative binomial distribution was used to account for zero-inflated data structure. Analyses were performed using the “lme4” package in R (Bates et al. 2015).

Tree seedling abundance was negatively associated with shrub cover (Fig. S1). The random effect of transect accounted for variation in seedling counts ($\sigma^2 = 1.148$), suggesting that site-specific factors influenced regeneration in addition to shrub cover. In our final structural equation model, these site-specific factors were included as topographic position index (TPI), fire severity, and forest structure covariates. Together, these results support the interpretation that shrub cover inhibited tree seedling regeneration.

Seedling abundance showed a non-linear relationship with topographic position, as indicated by a significant quadratic term. This indicates that seedling abundance may peak at intermediate topographic positions and decline at both high and low positions; in other words, regeneration was lowest on dry ridges and wet draws, and highest on mid-slope and flat positions. Fire severity, measured as average crown scorch, had a positive effect on seedling abundance, indicating that higher fire severity was associated with increased seedling regeneration (Fig. S2; Table S1). Our final structural equation model corroborated this direct positive effect and additionally found indirect negative effects of fire on seedlings.

Shrub cover was primarily influenced by fire severity and topographic position, with a

weaker association observed for tree basal area. Higher fire severity was linked to greater shrub cover, suggesting that intense fires may facilitate shrub dominance, while the positive effect of topographic position index indicates that shrubs were more abundant on drier ridgetops. In contrast, tree basal area had no relationship with shrub cover, indicating that tree basal area did not play a major role in determining shrub cover after fire and topography were controlled for (Fig. S2; Table S1).

Quantile regression analysis

We used mixed-model quantile regression to determine the thresholds at which total shrub cover, shrub diversity, average shrub height, tree basal area, fire severity, and TPI each affected seedling abundance by specifying 5th, 25th, 50th, 75th, and 95th percentiles. These were performed to test the assumptions of the SEM that coefficient estimates of predictors based on median abundance values did not significantly differ from those based on other quantile values. We included Transect ID as a random effect to account for spatial autocorrelation between quadrats. Analyses were performed using the package “lqmm” in R (Geraci 2014).

The influence of environmental factors on tree seedling abundance only varied slightly across different regeneration thresholds (Fig. S3). Shrub cover had a negative effect on seedling abundance at all but the 5th percentile, suggesting that denser shrub cover limits tree seedling regeneration across all seedling densities but with particular strength at higher seedling abundance levels. Fire severity was not a significant predictor at lower quantiles but became strongly influential at the 95th percentile, indicating that greater fire severity facilitated seedling establishment under the highest regeneration conditions observed. Shrub height and tree basal area showed no effects across most quantiles. Similarly, TPI and shrub diversity were not associated with seedling abundance at any quantile.

Tables and Figures

Table S1. Coefficients for univariate linear mixed models with Transect ID as the random intercept, where asterisk indicates significance at $\alpha = 0.05$ and TPI represents topographic position index.

Response	Predictor	Coefficient	
Tree Seedlings	Shrub Cover	$\beta_1 = -0.017$	*
Tree Seedlings	TPI + TPI ²	$\beta_1 = -0.235; \beta_2 = -1.867$	*
Tree Seedlings	Tree Basal Area	$\beta_1 = 0.213$	
Tree Seedlings	Fire Severity	$\beta_1 = 0.018$	*
Shrub Cover	TPI	$\beta_1 = 9.120$	*
Shrub Cover	Tree Basal Area	$\beta_1 = 2.567$	
Shrub Cover	Fire Severity	$\beta_1 = 0.249$	*

Table S2. Wilcoxon Signed-Rank test results displayed visually in Figure 2 (all guilds combined) and Figure S4 (individual guilds).

	Comparison	V statistic	P value	
All Guilds	All seedlings inside vs outside shrubs	21.5	< 0.001	*
	<i>Abies</i> inside vs. <i>Abies</i> outside shrubs	54.0	< 0.001	*
	<i>Pinus</i> inside vs. <i>Pinus</i> outside shrubs	59.0	< 0.001	*
	<i>Abies</i> inside vs. <i>Pinus</i> inside shrubs	286.0	0.020	*
	<i>Abies</i> outside vs. <i>Pinus</i> outside shrubs	421.5	0.167	
Xeric	All seedlings inside vs outside shrubs	9.5	0.013	*
	<i>Abies</i> inside vs. <i>Abies</i> outside shrubs	23.0	0.068	
	<i>Pinus</i> inside vs. <i>Pinus</i> outside shrubs	28.0	0.132	
	<i>Abies</i> inside vs. <i>Pinus</i> inside shrubs	67.5	0.362	
	<i>Abies</i> outside vs. <i>Pinus</i> outside shrubs	72.5	0.495	
Generalist	All seedlings inside vs outside shrubs	0.0	0.002	*
	<i>Abies</i> inside vs. <i>Abies</i> outside shrubs	1.5	0.006	*
	<i>Pinus</i> inside vs. <i>Pinus</i> outside shrubs	1.5	0.042	*
	<i>Abies</i> inside vs. <i>Pinus</i> inside shrubs	32.0	0.057	
	<i>Abies</i> outside vs. <i>Pinus</i> outside shrubs	42.5	0.423	
Riparian	All seedlings inside vs outside shrubs	0.0	0.006	*
	<i>Abies</i> inside vs. <i>Abies</i> outside shrubs	1.0	0.013	*
	<i>Pinus</i> inside vs. <i>Pinus</i> outside shrubs	0.0	0.009	*
	<i>Abies</i> inside vs. <i>Pinus</i> inside shrubs	13.5	0.136	
	<i>Abies</i> outside vs. <i>Pinus</i> outside shrubs	37.5	0.333	

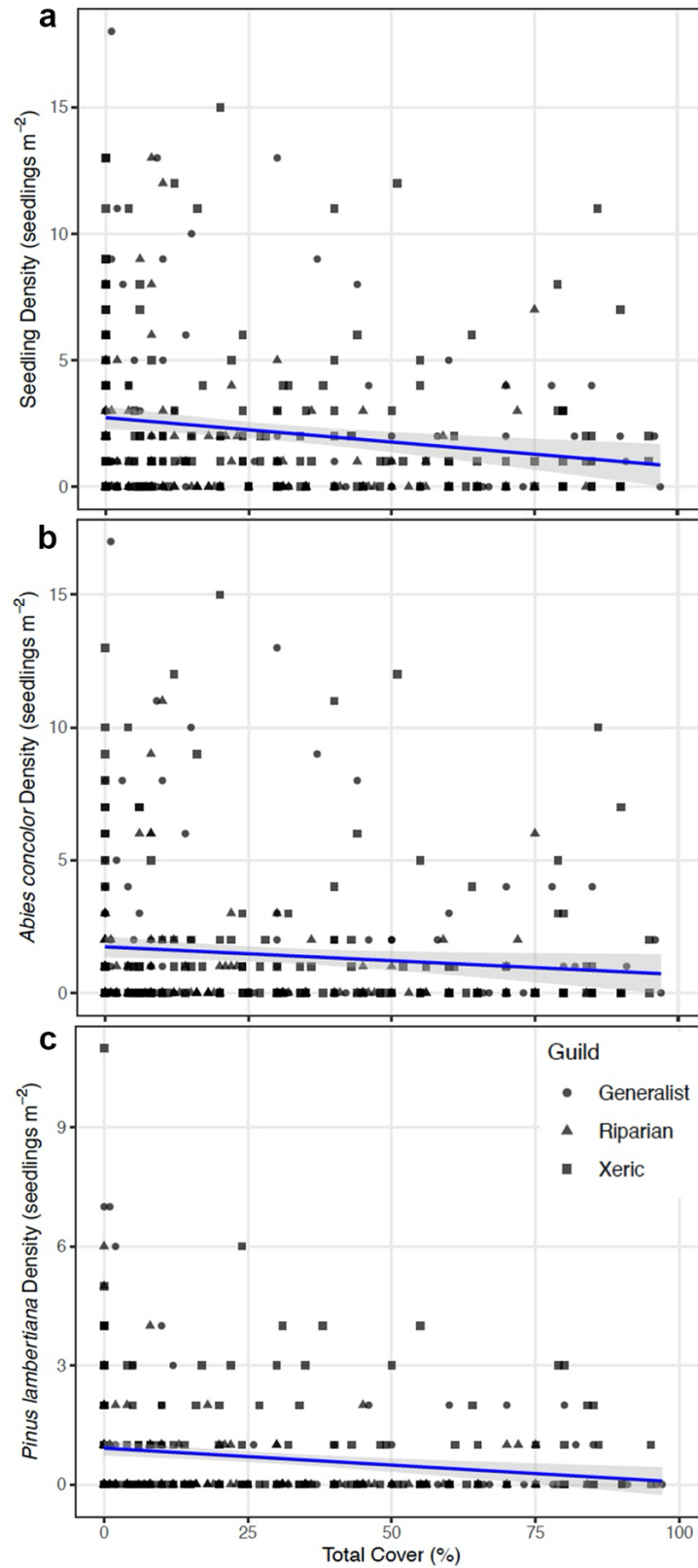


Figure S1. Linear relationship between shrub cover (%) and tree seedling density per quadrat for all seedlings (a), *Abies* (b), and *Pinus* (c). Blue line indicates significant linear trend at $\alpha = 0.05$.

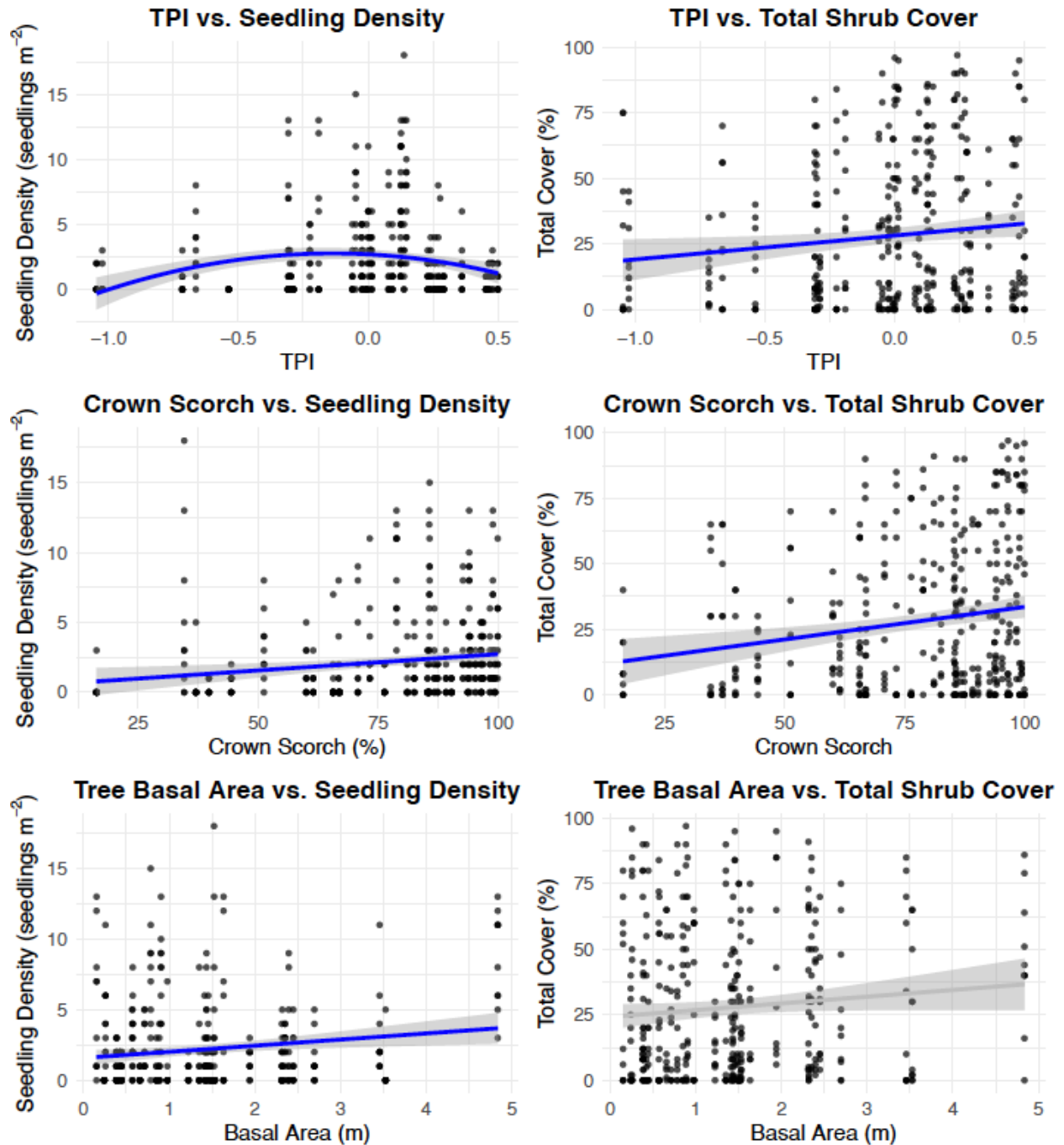


Figure S2. Individual relationships between shrub cover (%) and seedling density (# of tree seedlings m^{-2}) with TPI (topographic position index), fire severity (based on crown volume scorched), and tree basal area m^{-2} across each transect location. Blue line indicates significant linear trend at $\alpha = 0.05$.

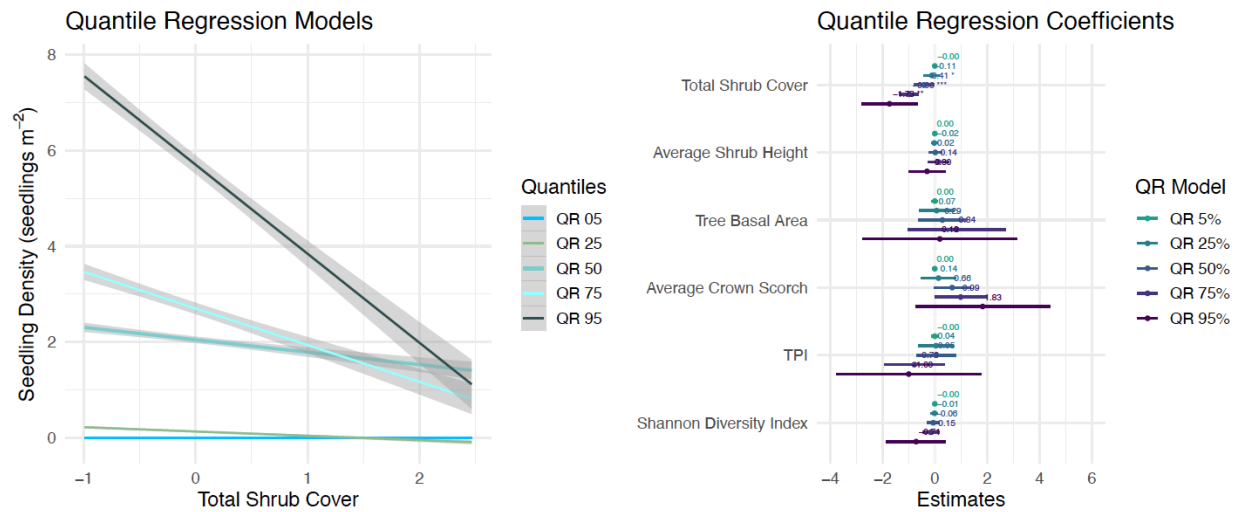


Figure S3. Quantile regression model and coefficient comparison across 5th, 25th, 50th, 75th, and 95th percentiles of seedling density. The effect of shrubs on seedling regeneration was most pronounced at the highest levels of regeneration (e.g., 95th percentile of seedling abundance has the steepest negative slope). However, coefficient estimates at median regeneration values did not significantly differ from other percentiles, so these were the focus of final structural equation models.

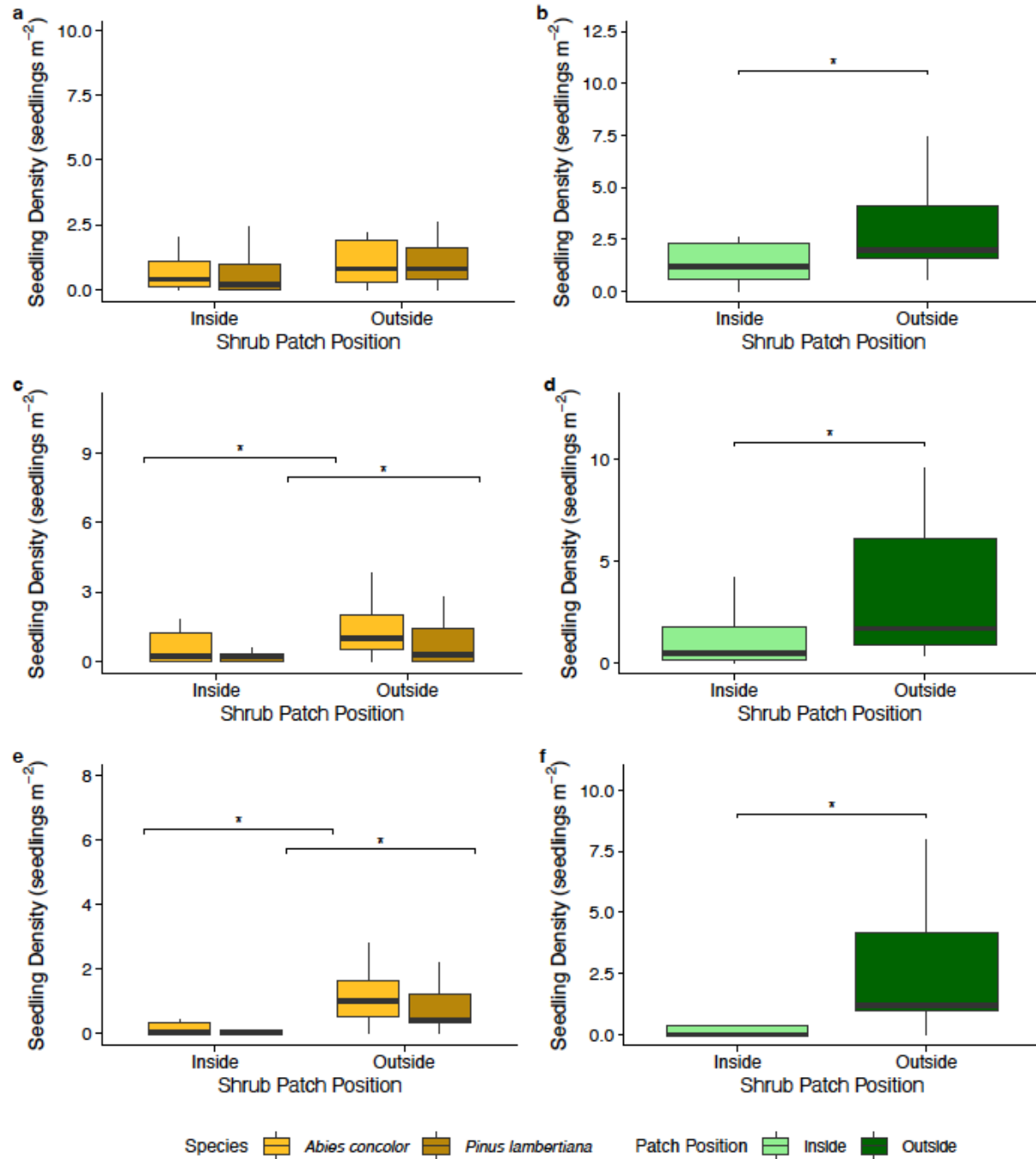


Figure S4. Tree seedling density per quadrat inside shrub patches (quadrats 0–5) and outside shrub patches (quadrats 5–10). Comparisons between species *Abies concolor* and *Pinus lambertiana* are shown within the xeric (a), generalist (c), and riparian (e) guilds; and comparisons inside and outside of shrub patches for all seedlings are shown within xeric (b), generalist (d), and riparian (f) guilds. Differences among groups were evaluated using Wilcoxon Signed-Rank tests, where asterisks (*) indicate significant differences among groups ($\alpha = 0.05$).

Supplemental References

- Bates, D., M. Mächler, B. Bolker, and S. Walker. 2015. Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software* 67:1–48.
- Geraci, M. 2014. Linear Quantile Mixed Models: The lqmm Package for Laplace Quantile Regression. *Journal of Statistical Software* 57:1–29.