SPATIAL PATTERNS AND MANAGEMENT IMPLICATIONS OF NATIVE BUNCHGRASS RECOVERY FOLLOWING OAK-PINE SAVANNA RESTORATION IN THE MID-ELEVATION OREGON CASCADES

by

EYRIE L. HORTON

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Student: Eyrie L. Horton

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Bart R. Johnson	Chairperson
Leslie Ryan	Member

and

Krista Chronister Vice Provost for Graduate Studies

Original approval signatures are on file with the University of Oregon Division of Graduate Studies.

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THESIS ABSTRACT

Eyrie L Horton

Master of Landscape Architecture

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Title: Spatial Patterns and Management Implications of Native Bunchgrass Recovery Following Oak-Pine Savanna Restoration in the Mid-Elevation Oregon Cascades

Restoring native grasslands by counteracting the forest succession which followed the loss of historical fire regimes is a vital component of landscape management in the Mediterranean moist climate of the western Pacific Northwest, USA. However, canopy cover reduction alone does not assure healthy grassland regeneration. Site-specific and species-level research is needed to identify effective restoration strategies. I examined two native bunchgrasses, *Festuca roemeri* and *Festuca californica,* in the Jim's Creek Restoration Area (Jim's Creek) to assess their relative success across varying microenvironmental and competitive gradients prior to and following restoration. To make these findings more accessible, I developed a handbook that employs a graphic language to make scientific research findings accessible to land managers and those who may not have a background reading statistics-based, ecological literature.

This thesis includes unpublished co-authored material.

CURRICULUM VITAE

NAME OF AUTHOR: Eyrie L Horton

GRADUATE AND UNDERGRADUATE SCHOOLS ATTENDED:

University of Oregon, Eugene
Westminster College, Salt Lake City

DEGREES AWARDED:

Master of Landscape Architecture, 2022, University of Oregon
Bachelor of Environmental Studies, 2018, Westminster College

GRANTS, AWARDS, AND HONORS:

David S. Easly Grant, University of Oregon, 2021
Outstanding Graduating Senior in Environmental Studies, Westminster College, 2018

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For Kaely, without whom none of this would have been possible.

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CHAPTER I: SPATIALLY EXPLICIT GRASSLAND RESTORATION MANAGEMENT

I intend to publish an adaptation of Chapter I of my thesis in an academic journal with co-authors Bart Johnson, Scott Bridgham, and Lindsey Kurtz. Bart Johnson and Lindsey Kurtz helped determine field, lab, and statistical procedures used in this work. Scott Bridgham provided data necessary for this project. I was responsible for the written text, and Bart Johnson served as the primary editor. I performed all analysis reported in the results and was a primary contributor to data collection and preparation.

INTRODUCTION

In the Pacific Northwest, USA, native grassland ecosystems are vital to human and non-human well-being. In the Willamette Valley Area of Western Oregon, grasslands support about 700 plant species, 400 of which are primarily or exclusively found in those habitats (Ed Alverson, The Nature Conservancy, unpublished data). Additionally, more than 1,100 arthropods rely on grasslands, 350-400 of which are species of native bees (Wilson, 1998). On top of supporting a wide array of species, native grasslands provide carbon sequestration, runoff and erosion control, and provide cultural value (Bengtsson et al., 2019).

Unfortunately, the once common native grasslands of Western Oregon have almost vanished. Prior to Euro-American colonization, indigenous peoples conducted cultural burning in Western Oregon to maintain grassland landscapes for a variety of reasons including acorn, camas, and grass collection as well as maintaining game ranges (Boyd, 1999; USDA, 2006). The cessation of indigenous burning due to their forced removal from the land, followed by fire suppression policies enacted in the early 20th century by the U.S. Forest Service and others, resulted in the loss of many remaining grasslands to forest succession (Bailey & Kertis, 2002; USDA, 2006).

Grassland restoration became a major conservation goal by the late 20th century, but best management practices are continually evolving. Grassland restoration following forest succession has particular complexities due to successional changes in ground layer structure and composition, as well as the soil disturbance caused by the tree removal activities. Perennial species are especially difficult to reestablish in restored grasslands (Buisson et al, 2020).

In contrast to perennials, many introduced grasses can colonize disturbed sites quickly and benefit from priority effects (Sheley, 1993; Dickson et al., 2012; Meyer et al., 2021). Even if invasive grasses are not abundant prior to restoration, machinery can bring in seeds of invasive species, and disturbance from machinery and logging slash creates opportunities for establishment (Brambila et al., 2021). The prevalence of introduced annual grass invasion of restored grasslands is likely to be amplified due to climate projections for Western Oregon, so it is critical that land managers take a hands-on approach from the beginning to assure healthy regeneration of grassland ecosystems (Pfeifer-Meister et al., 2016).

Each species' successful recovery in a restored grassland is dependent on the environmental suitability of the landscape for their life history mode. Individual species depend on the environmental conditions of their immediate surroundings, and slight changes in air temperature, soil moisture, and exposure will affect their success (Questad et al., 2014). While extensive restoration literature documents best management strategies and considerations, there is limited research on how individual species react to restoration activity on a microsite scale (Gornish & Santos, 2016; Maret & Wilson, 2005; Rook et al., 2011; Questad et al., 2014). A heterogeneous landscape requires a heterogeneous approach. Understanding the environmental requirements and life histories of key native species on microenvironmental scales can support more effective site planning and management over both the short and long terms.

To this end, I assessed the recovery of two native bunchgrass species in a restored oak-pine savanna grassland in the central Oregon Cascades to recommend fine-grained management strategies for the site. My goal was to develop an approach for identifying discrete, mappable land units that could be used to guide restoration efforts by statistically representing different levels of suitability for different species.

In this regard, I considered various approaches that use the spatial patterns of vegetation to map land units derived from site physical characteristics as a means to identify relatively stable topographic and edaphic configurations that underlie the current vegetation. While vegetation can be a relatively transitory phenomena, these site units can be used to classify and characterize microenvironmental heterogeneity that will continue to influence vegetation, and as such can be used as a site management unit. These approaches include concepts of ecotopes (Whittaker et al., 1973; Zonneveld, 1989; Runhaar and de Hayes, 1994), ecological site units (Barnes et al. 1982), landscape ecosystem groups (Lapin and Barnes 1995), and landscape phase units. In this project, I adopt the term ecotope to describe the identified land units on site.

I organized my research inquiries around three questions:

1) *In what types of biophysical and climatic microenvironments did each target species perform best?*
2) *To what degree was natural regeneration versus seeding important to their recovery post-restoration?*
3) *What generalizable lessons can be gleaned from matching species' life history and appropriate biotic, physiographic and climatic characteristics when creating a regional ecotope-based management?*

METHODS

Study Area Description

For over a decade, the U.S. Forest Service (USFS) has managed the 258-hectare Jim's Creek Restoration Area (Jim's Creek) as a test case for landscape-scale restoration of oak-pine savanna in the mid-elevation western Cascades. Located in the Willamette National Forest, the site comprises predominantly south to southwest facing slopes that range from 600 m elevation adjacent to upper Middle Fork Willamette River to 1050 m at the ridgetop.

Prior to Euro-American colonization, indigenous peoples used Jim's Creek as a summer camp and appear to have managed the landscape through fire stewardship, cultivating an oak-pine savanna (USDA, 2006). Dendrochronological and phytolith evidence strongly suggests that, as recently as the mid-1800s, Jim's Creek was predominantly a savanna grassland with scattered Oregon white oak, ponderosa pine and Douglas-fir embedded in a matrix of native grasses and forbs (Day, 2005; Kirchholtes, 2006).

However, by 2000 Jim's Creek had become a largely closed canopy conifer forest with small grassland remnants on only 5% of the site. In many areas, trees were as dense as 300-600 per acre. When the Jim's Creek restoration project was conceived, it was driven by the exigency of protecting large oaks and pines that were rapidly dying under the successional infill of Douglas-fir. 45% of large oak and 44% of pine were already dead and many more were in steep decline.

Beginning in 2003, University of Oregon (UO) and USFS researchers set up five stratified-random belt transects to assess both contemporary vegetation structure and distribution, and successional trajectories since Euro-American settlement (circa 1850). A total of 3300 m of 30 m wide transects were established. In addition, 200 m^2 circular plots were established every 30 m to assess ground layer vegetation and small-tree density, creating a total of 128 transect plots, supplemented with 15 purposively selected (and randomly offset) meadow and forest-meadow transition plots to obtain adequate sample sizes.

From 2008-2010, ~90% of small trees were removed via thinning, reducing average canopy cover by 40% in thinned areas. All oaks, pines, and Douglas-fir trees larger than 75 cm diameter at breast height (DBH) were retained. Major ephemeral drainages on the lower half of the slope were uncut due to concern for federally listed Brook Trout recovery. After restoration, the majority of Jim's Creek was converted from forest to oak-pine savanna and woodland; in thinned areas, ground layer cover of grasses and forbs increased over 15-fold as forest and woodland understories converted to grassland.

Jim's Creek restoration, like many restoration projects begun in the late 20th century, was conceived when the predominant model was still that of helping a system return to a prior condition. Furthermore, although regular prescribed fire was planned to sustain a savanna structure and to support fire-adapted native grasses and forbs, there was substantial debate around whether seeding or other management was needed to assist ground layer recovery. Broadcast seeding of grasses and forbs was considered but at that time there was no capacity to locally collect and bulk out sufficient seed for a project of this scale. Because the imperative to thin dense young trees before further mortality of legacy oaks and pines was the restoration's high priority, only a very small number of plots were able to be seeded out as a ground layer recovery experiment.

Following thinning, twenty 200-m^2 plots were seeded with a mixture of 8 native prairie species, including two grasses, Roemer's Fescue (*Festuca roemeri*) and California fescue (*Festuca californica*), to compare the results to those of natural regeneration. Mistakenly, the invasive introduced grass species tall fescue (*Schedonorus arundinaceus*) was mistaken by seed collectors for the California fescue, grown out by producers and seeded into the plots, resulting in an unintended test of two perennial grasses, one native and one introduced.

Data Collection & Field Methods

<u>Ground Layer Sampling (2006, 2020).</u> Plant cover < 1 m high was measured using the point intercept (PI) method (Elzinga et al., 1998). Within each 200 m^2 (7.96 m radius) plot, two measuring tapes were set out in a "X" that crossed the plot center, arranged SW-NE and SE-NW. Beginning 6 m from plot center, a 1.3 m 3/16" steel pin was released from above the ground layer canopy perpendicular to the ground every 0.5 m, avoiding a 1 m radius circle

at plot center where other measurements could trample vegetation, for a total of 40 points/plot. Each time a plant touched a pin, it was identified by species and counted. Each "hit" thus constituted 1/40 = 2.5% cover. In cases where plant canopy was layered, more than 100% cover was possible. A thorough assessment of the entire plot was also made to create a full species list. Each species that was encountered in the plot but not hit by a pin was assigned 0.25% (trace) cover.

<u>2021 Air Temperature</u>. We collected temperature data using IButtonLink DS1921G-F5# Thermochron fobs (https://www.ibuttonlink.com/collections/ibutton-fobs) installed in all 145 8-m^2 circular plots (30 m apart) along 5 transects within Jim's Creek and 17 transect plots plus 6 purposive plots in an untreated comparator size immediately adjacent to Jim's Creek. We mounted iButtons on 6"x6" plywood shelters oriented south at a slight angle to the ground to prevent water pooling and block direct late-afternoon sun. iButton data were collected from April 20th, 2021 to October 3rd, 2021, capturing the growing season from spring dry-down through the Mediterranean summer drought until the initiation of the fall rainy season. See Appendix S Table 1.1 for the full temperature variable list.

<u>2021 Soil Moisture.</u> Soil moisture was measured five times during the growing season using round wooden dowels as soil moisture probes by adapting the protocols of Johnson (1995). Five poplar dowels were placed systematically in each plot for relocation, one ~1 m east of plot center and four

3 meters to each cardinal direction, offset 1 meter clockwise to avoid the transect line. Holes were preset by pounding a 5/16" metal rod into the soil using a dead blow hammer to reduce rebound. If an obstruction was encountered the probe was relocated up to 5 times (marking each attempt with a pin flag) until a 20 cm depth could be achieved. If a 20 cm depth was not achieved, the deepest hole was selected, and the dowel was clipped to that length and inserted. Because the preset hole was intentionally smaller than the dowel, probes needed to be hammered into the soil and achieved tight contact with the soil.

At the time of sampling, all five probes in a plot were carefully retrieved by pulling straight up with pliers to avoid disturbing the hole. Each probe was immediately placed in a labeled plastic vial (one for each plot) and sealed with a plug and a cap to ensure an airtight and water-vapor-tight seal; simultaneously each probe removed was replaced with another one of the appropriate length. The soil was firmed around each new probe by pressing with pliers or the hammer to ensure a tight seal, especially around the top. Although probes were expected to equilibrate with soil moisture along the length of the probe within 48 hours, protocols were to leave them for a minimum of one week.

In the lab, each sealed vial was weighed and recorded. The five dowels from each plot were removed, placed in a labeled bag and dried at 60° C. Each tube with its plug and cap was placed in a labeled paper bag for air drying. After a minimum of 48 hours, we weighed each set of 5 dowels and associated container to assess their relative moisture content as water weight (g) /dowel dry weight (g). Samples were collected on 5/9, 5/29, 7/2, 8/29 and 10/3/21. See Appendix A for dowel selection and tensiometer calibration methods.

2021 Biomass and Fitness Sampling. My team and I collected field measurements and plant samples for perennial target species *Festuca californica*, *Festuca roemeri* and introduced *Schedonorus arundinaceus* at peak biomass and when grass seeds were ripe. To bracket the full range of abundance of each perennial grass recorded during 2020 PI ground layer sampling, we collected biomass from forty-eight of the permanent plots situated within the same area as the 200 m^2 (7.96 m radius) plots used for PI sampling. Each circular plot was organized into four quadrants. We placed one pin flag in each quadrant 4 m from plot center. We then located the nearest individual of each target species in each quadrant and measured distance from the plant to the flag, major and minor axis of the plant, longest vegetative leaf, number of flowering stems, longest flowering stem, and distance from the plant to any nearest target species. When possible, we collected full plant biomass clippings of each species. In lab, we weighed dried biomass, measured flowering stem length, and counted seeds and flowering stems.

Data Preparation

Missing Temperature Value Estimation. During the 2021 process of collecting temperature data using the iButtons, multiple sensors were lost in the field due to elk activity or malfunctioning sensors that failed to collect data. Because we reset the iButtons several times throughout the data collection period, none of the plots were missing data for the entire period. To estimate the missing values, my team and I compared the surviving plot temperatures to all other sensor readings using Tableau (Tableau 2021.4, 20214.22.0352.1233) software. We used the sensor with the closest readings to estimate the temperature observations for the missing period. When multiple sensors were found to be good candidates, the sensor closest geographically to the site with missing data was used.

Allometric Estimation Equations. Using the subsample of target species for which biomass and flowering stems were collected, I estimated biomass and fitness through allometric equations using linear regression. Initially, I ran correlation models to identify any collinearity among independent variables and to help guide linear regression tests. With the Leaps package in R-Studio 2021.09.0 Build 351, I identified the best ten 1-5 variable models and selected final models based on r^2, p-value, and distribution of residuals. If no good model candidates existed for measures of fitness, I estimated fitness by multiplying the average florets per flowering stalk of the species by the number of flowering stalks. See Appendix S Table 1.2 for full allometric equations.

I then calculated species density by plot using field measurements of meter distance from measured plant sample to pin (d_met). Density was calculated as:

1/(Pi*d_met)^2

Next, I multiplied plot average sample biomass and fitness measures by plot average density to calculate total estimated plot biomass and fitness per species.

To identify the relative success of *F. roemeri* over *S. arundinaceus*, I subtracted *S. arundinaceus* plot biomass from *F. roemeri* plot biomass.

<u>Introduced Annual Grasses.</u> I identified the introduced annual grasses by selecting the introduced annual grass species found during 2006 and 2020 PI recording, *Lolium multiflorum, Cynosurus echinatus, Bromus tectorum, Bromus hordeaceus, Bromus commutatus,* and *Aira caryophylla*. Most introduced annual grasses on site are species *Cynosurus echinatus* and *Bromus hordeaceus*; these species comprise 38% and 54% respectively of the entire introduced annual grass cover.

<u>*Festuca californica vs. Festuca roemeri* Success</u>. To analyze the different environmental requirements of the two target species post-restoration and better understand how to create a seeding strategy, I created a success variable calculated as:

2020 Festuca californica PI cover – 2020 Festuca roemeri PI cover

This variable indicates where one species outperformed another, with positive results showing *F. californica* success and negative showing *F. roemeri* success.

Data Analysis

Data Visualization. I used Tableau (Tableau 2021.4, 20214.22.0352.1233) software to explore the data through visualization.

Target Species Categorical and Regression Tree (CART). I conducted analysis using R-Studio 2021.09.0 Build 351. Initially, I ran CARTs (R package Rpart) with all variables (see Appendix S Table 1.3) in the data set and noted variables that were found to be used early in the tree splitting. Next, I used the same dependent variable as the CART to identify the best regression model candidates (R package Leaps, function regsubsets). Variables that were most often found in models were then tested in the CART against the variables noted during the initial CART run. I tested different variable combinations until I could identify a strong model that matched field observations. Covariates were not included in a single CART. To reduce the risk of overfitting to the data, the optimal model was pruned considering the Complexity Parameter (CP).

Target Species Post-Restoration Cover Change Regression. I conducted analysis using R-Studio 2021.09.0 Build 351. I identified the best models (R package Leaps function regsubsets) and selected the optimal model based on

r^2, P-value, distribution of residuals, and term significance. No model includes variables that share a correlation coefficient above .6.

Experimental Seeded Plot Regression and Akaike Analysis. I conducted analysis using R-Studio 2021.09.0 Build 351. To assess potential variables of importance, I ran correlation matrices (R package Corrplot, spearman method) of temperature and moisture variables as well as all physical environmental variables. I then identified the best potential models (R package Leaps, Regsubsets function). Best models were selected based on r^2, P-value, distribution of residuals, and term significance. No model includes variables that share a correlation coefficient above .6.

I found multiple candidate models to be strong contenders, so I ran an Akaike on variables most suggested by the best potential models (R package MuMIn, dredge function). I assessed models with an AICc within 7 points of the best model based on variable p-values, r^2, and residual distribution. I then excluded models with insignificant variables and reran the Akaike. This process continued until all models under 7 AICcs of the best model included only significant terms. All selected models indicated a shared outlier. I ran Akaike and Linear regression tests without this outlier to assess its impact.

RESULTS

Festuca roemeri

Post-Restoration Change (PI data). Before restoration, *F. roemeri* was present in 16 of 82 plots, six of which were listed as trace cover, with an average cover of 6.5% when present. On average in sampled plots, *F. roemeri* produced 293 florets/m^2, with the highest plot producing 1056 florets/m^2. The average biomass recorded was 9.7 grams and the largest plant individual measured was recorded at 62 grams with a basal area of 259 cm.

Of the plots not seeded, *F. roemeri* naturally established post-restoration in 1/8 plots that had open canopy (prairie, savanna, or open woodland community types) prior to restoration, and 2/38 plots that had closed canopy (closed woodland or forest) (Table 1.1).

Festuca roemeri was seeded in 18 plots after restoration. Four seeded plots were unsuccessful due to swift infill of shrubs. Excluding these plots, seeding increased *F. roemeri* cover. On average *F. roemeri* increased by 1.25% cover in unseeded plots but increased by 64% cover in seeded plots. *Festuca roemeri* was present in the 16 seeded plots and 15 unseeded plots in 2020 (Table 1.2). The average cover in the seeded plots was 30 times more than in the unseeded plots.

Sixteen thinned plots were seeded; within these plots, *F. roemeri* increased cover most in areas where surface rock was present, annual grass cover was lower, and silt percent was lower (r^2 =.45, $p< 0.09$).

$$Y_i = 261.9480 + -5.1275(\%\ \text{silt}) + -1.1905\ (\text{total annual grass cover}) + 47.5414\ (\text{surface rock})$$

Table 1.1: Festuca roemeri Unseeded Post-Restoration Cover Change*. This matrix tracks the change in F. roemeri cover pre-post-restoration in pre-restoration open and closed canopy, to post-restoration thinned and unthinned plots. Percentages are within groups of total open canopy, closed canopy, thinned, and unthinned plots.*

		2020 Thinned			2020 Unthinned					
2006 Canopy Closure	**Grass cover class**	**Absent**	**Trace**	**>Trace**	**Absent**	**Trace**	**>Trace**	**2006 (total)**	**2006 (%)**	
Open Canopy	**Absent**	**4**	0	0	**3**	0	1	8	40%	Total: 100%
Open Canopy	**Trace**	0	**0**	1	0	**1**	1	3	15%	
Open Canopy	**>Trace**	0	0	**0**	0	2	**7**	9	45%	
Closed Canopy	**Absent**	**34**	2	0	**2**	0	0	38	95%	Total: 100%
Closed Canopy	**Trace**	1	**0**	0	0	**0**	0	1	3%	
Closed Canopy	**>Trace**	0	1	**0**	0	0	**0**	1	3%	
	2020 (total)	39	3	1	5	3	9			
	2020 (%)	91%	7%	2%	29%	18%	53%			
			Total:	100%		Total:	100%			

Table 1.2: Comparison of 2020 Festuca roemeri (FR) *cover and plot presence in plots with and without seeding and with and without presence in 2006. Mean 2020 % cover is the average cover by plot in seeded and unseeded plots. This table only includes plots where FR is present in 2020 (total = 31)*

	# of Plots FR Present 2006	**# of Plots FR Absent 2006**	**Total Plots**	**Mean 2020 % Cover**
# of Seeded plots FR present 2020	4	12	16	68.7%
# of Unseeded, plots FR present 2020	12	3	15	2.4%

CARTs (PI data). Prior to restoration, *F. roemeri* cover depended on canopy cover (Fig. 1.1, r^2 = .39). It grew best where canopy cover was below 19% (mean = 9%). Where canopy cover was between 19-37% (mean = 1.5%), *F. roemeri* did not do well, and canopy cover above 38% rarely supported any *F. roemeri* (mean = .29%). There were two trace and one > trace observation in a group of 16 total observations. Above 55% canopy cover almost never support *F. roemeri* (mean =.017%). There is only one trace observation out of 28 total observations in this category.

Post-restoration, *F. roemeri* was able to increase cover and to colonize new areas (Fig. 1.2, r^2 = 0.53), but only where it was already established in 2006 or where it was seeded. Seeding was the most important factor controlling post-restoration cover (mean 2020 cover = 85%). It also did reasonably well where it was not seeded but had been present at 4% or greater cover prior to restoration (mean = 16%). When not seeded and present at low cover or absent in 2006, *F. roemeri* did poorly in areas with soil depth below or equal to 36 cm (mean = 1.3%). It did worst in areas with soil depth >36 cm (mean cover = .08%). In this leaf node, there were one > trace and two trace observations out of a total of 35.

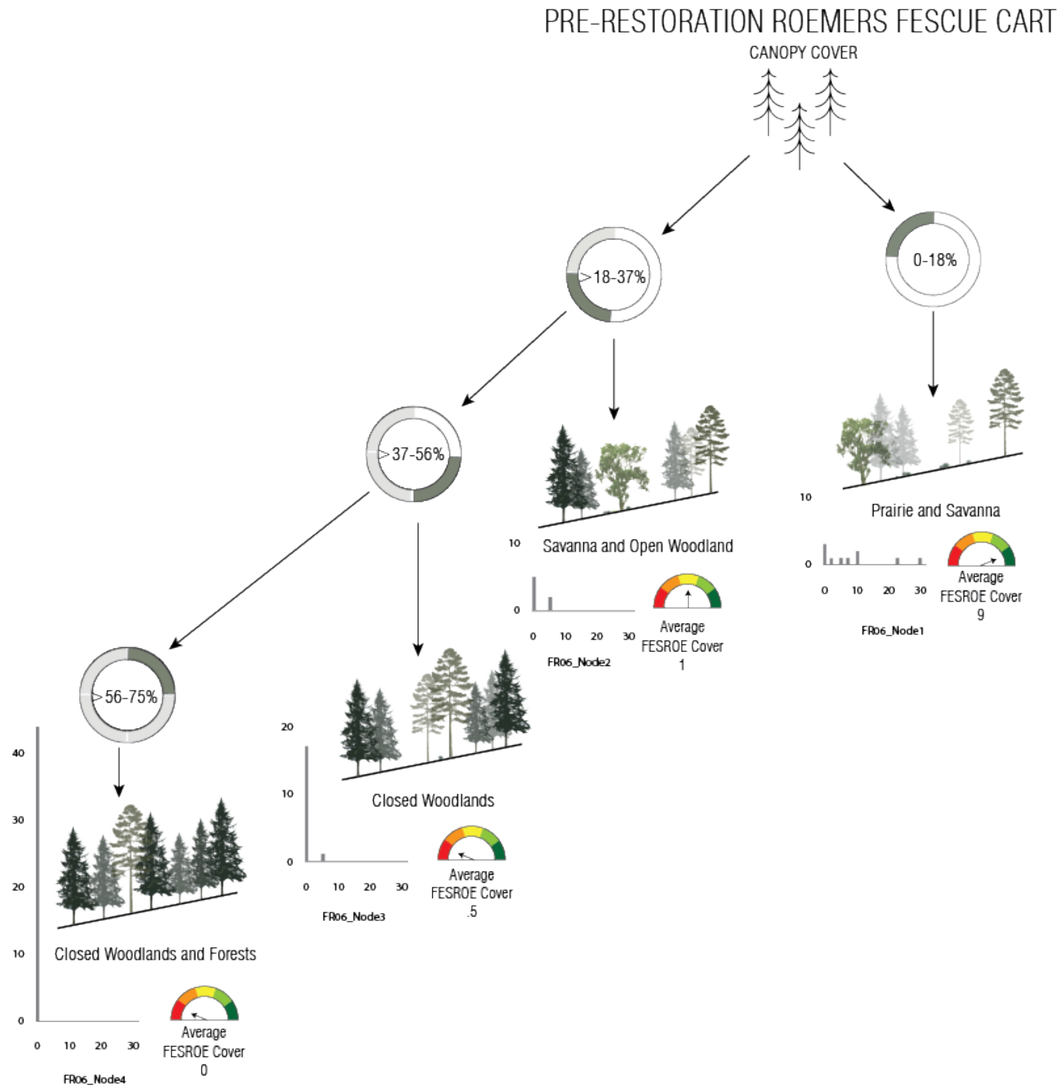


Figure 1.1: Pre-restoration Festuca roemeri CART. *Festuca roemeri success depends on canopy cover. Histograms indicate node distribution. This Illustration is an interpretation of the results. Each leaf/node of the CART is accompanied by a graphical representation of the landscape, variable value, distribution of plot values and a dial showing the outcome for the dependent variable.Original CART output in Appendix S Figure 1.1.*

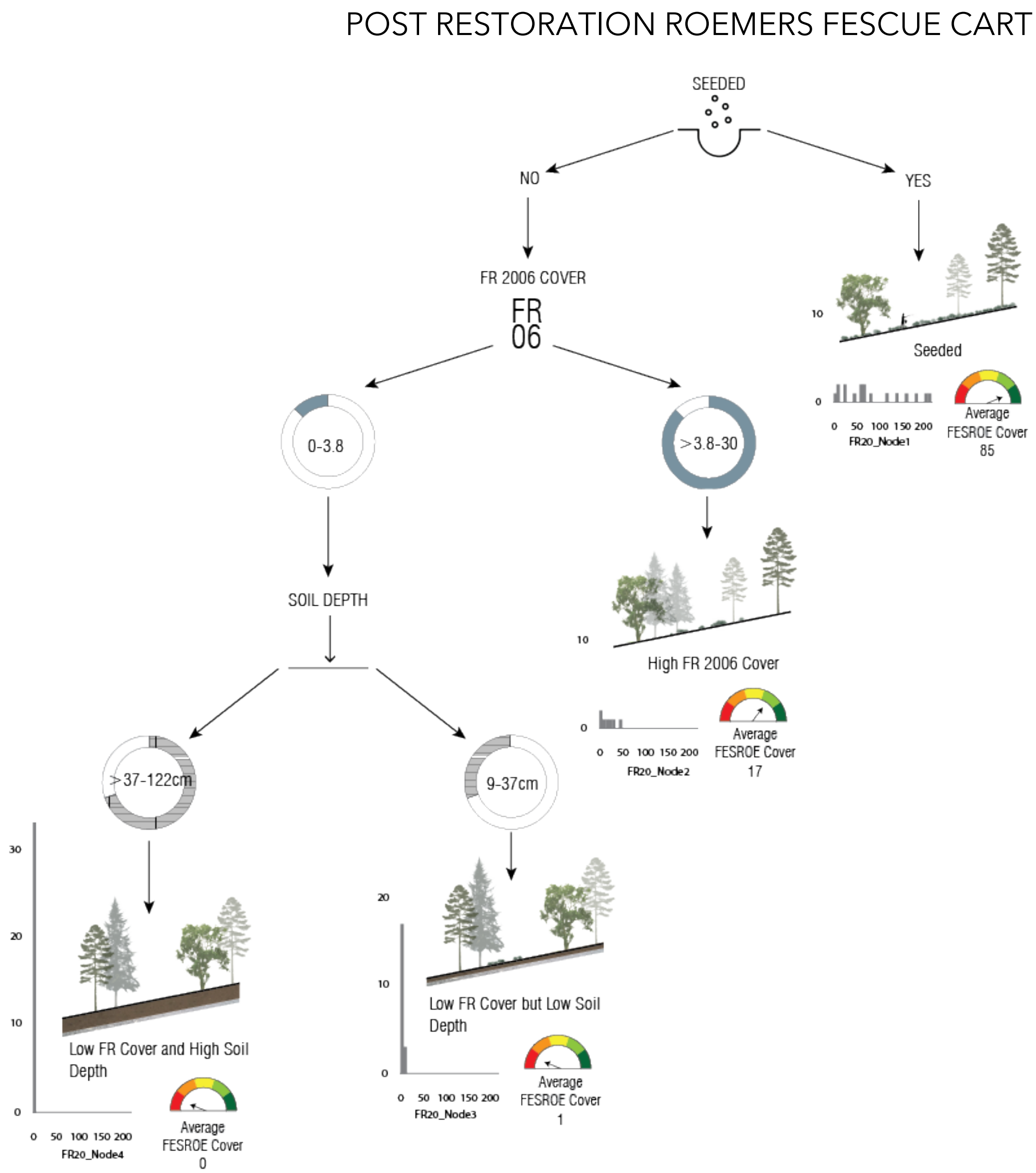


***Figure 1.2:* Post-restoration *Festuca roemeri CART*.** *Festuca roemeri responds well to seeding and expands where it was present before. Higher soil depth is associated with lower F. roemeri. Histograms indicate node distribution. This Illustration is an interpretation of the results. Each leaf/node of the CART is accompanied by a graphical representation of the landscape, variable value, distribution of plot values and a dial showing the outcome for the dependent variable.Original CART output in Appendix S Figure 1.2.*

Seeding Experiment (Biomass data). Of the 16 seeded plots where either *F. roemeri* or *S. arundinaceus* were able to establish, the combined cover of *F. roemeri* and *S. arundinaceus* was 139% on average, constituting an average of 41% of the total groundlayer in a plot. Where not seeded, the combined cover of *F. roemeri* and *S. arundinaceus* was 4.6% on average, constituting an average of 1.8% of the total groundlayer

Festuca roemeri outperformed *S. arundinaceus* in 11/16 plots, with an average cover of 90%, while *S. arundinaceus* had an average cover of 49%. *Festuca roemeri* outperformed *S. arundinaceus* most where both moisture and temperature were lower. I identified four competing models (Table 1.3). All models shared two common outliers that were extremely high *F. roemeri* success measures. These models followed the pattern of the rest of the data, but not linearly. As a result, I removed these outliers. Table 1.3 shows the model results once these outliers were removed.

Table 1.3: Akaike Model Candidates for Seeded Plot Analysis*. Full table with and without outlier included in Appendix S Table1.4. See Appendix S Table 1.5 for full equations.*

Model	Model Variables	AICc	R^2	p-value
A	(-)MeanM_Spr + (-)Mean_MinT_12hd_Grw	152.7	0.77	0.0001
B	(-)MeanM_Spr	157.2	0.61	0.0005
C	(-)MeanM_Sum	157.4	0.61	0.0005
D	(-)MeanM_Sum + (-)MeanT_Spr	157.7	0.69	0.001

Festuca roemeri success in seeded plots was primarily driven by spring and summer soil moisture. In both models, higher soil moisture led to lower *F. roemeri* success (Figure 1.3). Both hot season moisture and spring season moisture improved model performance with the introduction of a temperature variable. In both cases, success has a negative relationship with temperature variables, with higher temperatures indicating lower *F. roemeri* success.

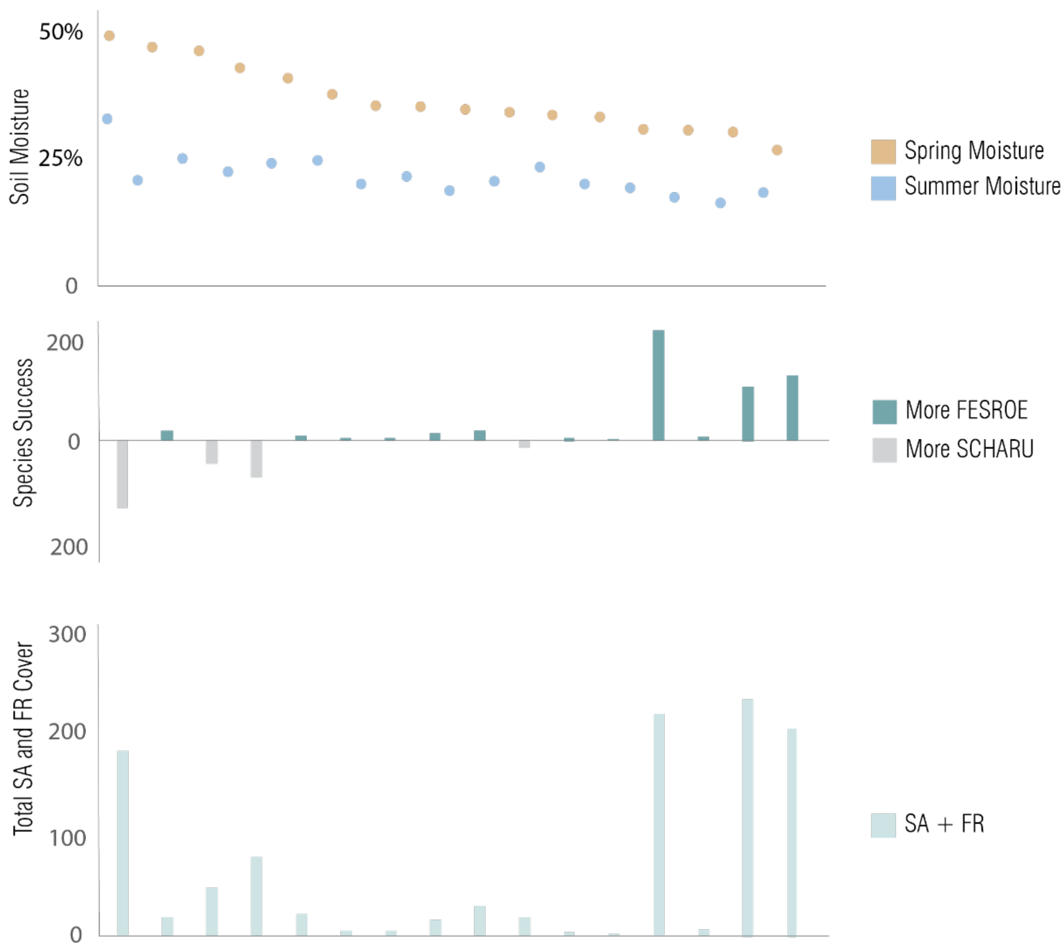


Figure 1.3:Seeded Plot Festuca roemeri Success Graph. *Festuca roemeri outperformed S. arundinaceus in drier environments, following spring moisture closest.*

<u>Introduced Annual Grasses Vs. *Festuca roemeri* (PI data).</u> Similar to *F. roemeri,* introduced annual grasses increased following canopy thinning, but

increases were much greater and included plots where they were not present prior to thinning. Seeding significantly increased *F. roemeri's* ability to outperform the introduced annual grasses; *F. roemeri* outperformed introduced annual grasses in 1/30th of the unseeded plots in contrast to outperforming them in 2/3^{rds} on the seeded plots. In these seeded plots, *F. roemeri* was more likely to outperform introduced annual grasses in plots with deeper soil depth. On average, soil depth in plots where *F. roemeri* outperformed the introduced annual grasses was 58.7 cm. In contrast plots where it did not outperform the annual grasses had an average soil depth of 40 cm. Prior to restoration and unseeded, *F. roemeri* preferred areas with minimal annuals present (r^2 =.23, $p < 8.17e-06$).

Festuca californica

Post-Restoration Change (PI Data). *Festuca californica* was present in 48 plots prior to restoration, 31 of which were listed as trace. Post-restoration, cover increased by 500% across all plots. On average, *F. californica* produced 31 seeds/m^2, with the highest plot producing 682 seeds/m^2. The average biomass recorded was 25 grams and the largest plant individual measured was recorded at 120 grams with a basal area of 633 cm^2.

In originally open canopy plots, *F. californica* did not establish if it had not been present prior and did not increase if present in trace amounts pre-restoration (Table 1.4). Four plots listed *F. californica* as > trace prior to restoration in open canopy, but all of these decreased to trace or absent after restoration. It should be noted that thinning operations produced substantial ground layer disturbance in some areas due to the sheer number of trees that were felled and removed, and the thick layers of slash left on the ground, which was subsequently piled and burned. Subsequent pile burning could also produce localized impact through their sustained heat and creation of bare soil. This makes the increases of *F. californica* in thinned areas even more notable and could explain some of the declines.

In originally closed canopy plots, *F. californica* established in two plots it had not been observed in before, and 11/27 plots increased from trace to >trace after restoration. All increases occurred in previous closed canopy, thinned plots. Overall, however, *F. californica* showed increases to an average of 7% in plots where it was recorded as trace in 2006 and an average increase of 15% in plots with >trace.

Presence in 2006, higher summer soil moisture, lower growing season minimum temperatures, and conversion from closed woodland to a savanna all caused greater increases of *F. californica* cover. (r^2 = .27, p< 001).

Yi = 39.0540 + 1.3190(F. californica 2006 % cover) + 256.8049 (summer soil moisture) +14.0630 (Closed Woodland – Savanna) + -9.9416(growing season minimum temperatures)

Festuca californica vs. Seeded Species (PI data). Although I was not able to directly compare seeding of *F. roemeri* and *F. californica* due to the collection of the wrong species (*S. arundinaceus*), the two plots with high 2006 *F. californica* cover (38% and 32%) were both seeded plots. In both cases, *F. californica* outperformed both seeded species in 2020, having doubled and tripled its cover post-restoration respectively. In one plot *F. roemeri* and *S. arundinaceus* seeding failed completely (the only other plot where seeding failed was taken over by shrubs); in the other plot, *F. californica* cover was greater than that of *F. roemeri* and *S. arundinaceus* combined. In three of six other seeded plots where *F. californica* was present in at least trace amounts in 2006 it was co-dominant with one or both of the seeded grasses in 2020. It was also a co-dominant in two seeded plots where it was not recorded in 2006. Thus, *F. californica* was a dominant or co-dominant bunchgrass in 7 of 20 seeded plots despite it not being seeded.

Table 1.4: Festuca californica Post-Restoration Cover Change*. This matrix tracks the change in F. californica cover pre-post-restoration in pre-restoration open and closed canopy, to post-restoration thinned and unthinned plots. Percentages are within groups of total open canopy, closed canopy, thinned, and unthinned plots.*

		2020 Thinned			2020 Unthinned					
2006 Canopy Closure	**Grass cover class**	**Absent**	**Trace**	**>Trace**	**Absent**	**Trace**	**>Trace**	**2006**	**2006(%)**	
Open Canopy	**Absent**	**2**	0	0	**11**	0	0	13	65%	Total: 100%
Open Canopy	**Trace**	0	**1**	0	0	**2**	0	3	15%	
Open Canopy	**>Trace**	0	2	**0**	1	1	**0**	4	20%	
Closed Canopy	**Absent**	**13**	0	2	**0**	N/A	0	15	26%	Total: 100%
Closed Canopy	**Trace**	0	**13**	11	N/A	**3**	N/A	27	47%	
Closed Canopy	**>Trace**	1	3	**11**	0	0	**1**	16	28%	
	2020 (total)	16	19	24	12	6	1			
	2020 (%)	27%	32%	41%	63%	32%	5%			
			Total:	100%		Total:	100%			

<u>CARTs (PI data).</u> Because I didn't find a single CART model which robustly addressed all the dynamics at play for pre-restoration *F. californica*, I ultimately selected two models. The first uses percent silt and soil depth (r^2 = .12) and the second uses percent silt and canopy cover (r^2 =.17). In the pre-restoration *F. californica* CART 1 (Fig. 1.4), *F. californica* established and thrived where percent silt was above 45.9% (mean = 8.6%). It performed adequately in lower silt environments with soil depth above 66 cm (mean = 4%). It did worst in low silt environments with soil depths below 65.7 (mean = 1.2%).

For the pre-restoration *F. californica* CART 2 (Fig. 1.5), the first split, percent silt, remains identical to CART 1, but the second split identifies canopy cover instead of soil depth (r^2 = .17). When silt was below 46%, if canopy cover was below 45%, *F. californica* showed higher cover (mean = 7%). In comparison, in plots with silt below 46% and canopy cover above 45%, *F. californica* did much worse on average (mean = 1%).

The third CART (Fig. 1.6) considers *F. californica's* 2020 post-restoration cover (r^2 =.37). *Festuca californica* had the highest cover in areas where it had existed before restoration which experienced above 32% moisture on average during the growing season (mean = 54%). However, *F. californica* did much worse in areas with soil moisture below 32%, even if it had been observed in those locations previously (mean = 8.4%). If not present pre-restoration, *F. californica* had a chance of establishing and spreading moderately if soil depth was above 73 cm (mean = 14%) but saw limited establishment if soil depth was below that threshold (mean = 2.9%).

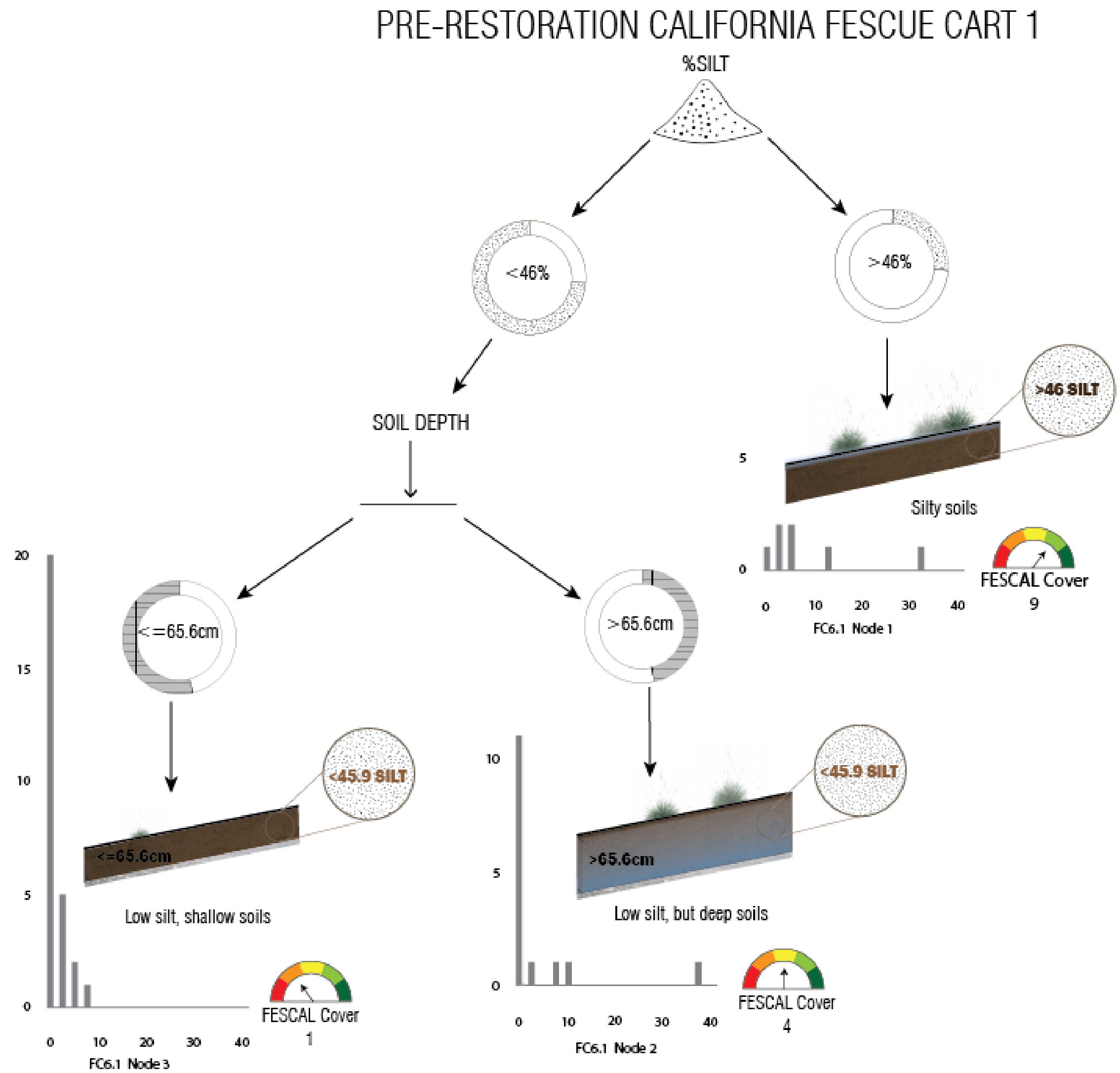


Figure 1.4: Pre-restoration Festuca californica CART 1. *Festuca californica establishes in high silt or deep soil environments. Histograms indicate node distribution. This Illustration is an interpretation of the results. Each leaf/node of the CART is accompanied by a graphical representation of the landscape, variable value, distribution of plot values and a dial showing the outcome for the dependent variable.Original CART output in Appendix S Figure 1.3.*

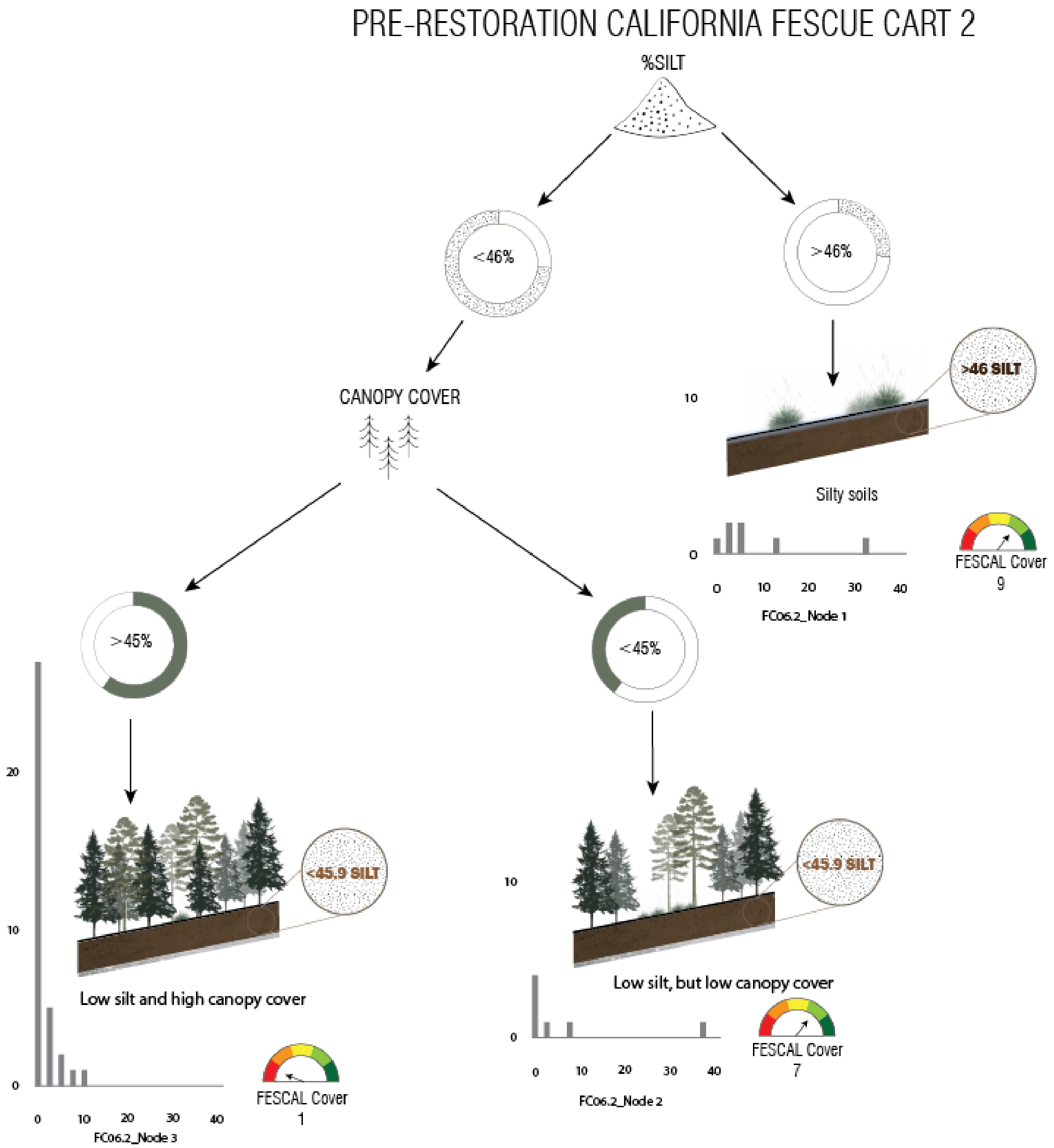


Figure 1.5. Pre-restoration Festuca californica CART 2. *Festuca californica responds negatively to high canopy cover when silt is low. Histograms indicate node distribution. This Illustration is an interpretation of the results. Each leaf/node of the CART is accompanied by a graphical representation of the landscape, variable value, distribution of plot values and a dial showing the outcome for the dependent variable.Original CART output in Appendix S Figure 1.4.*

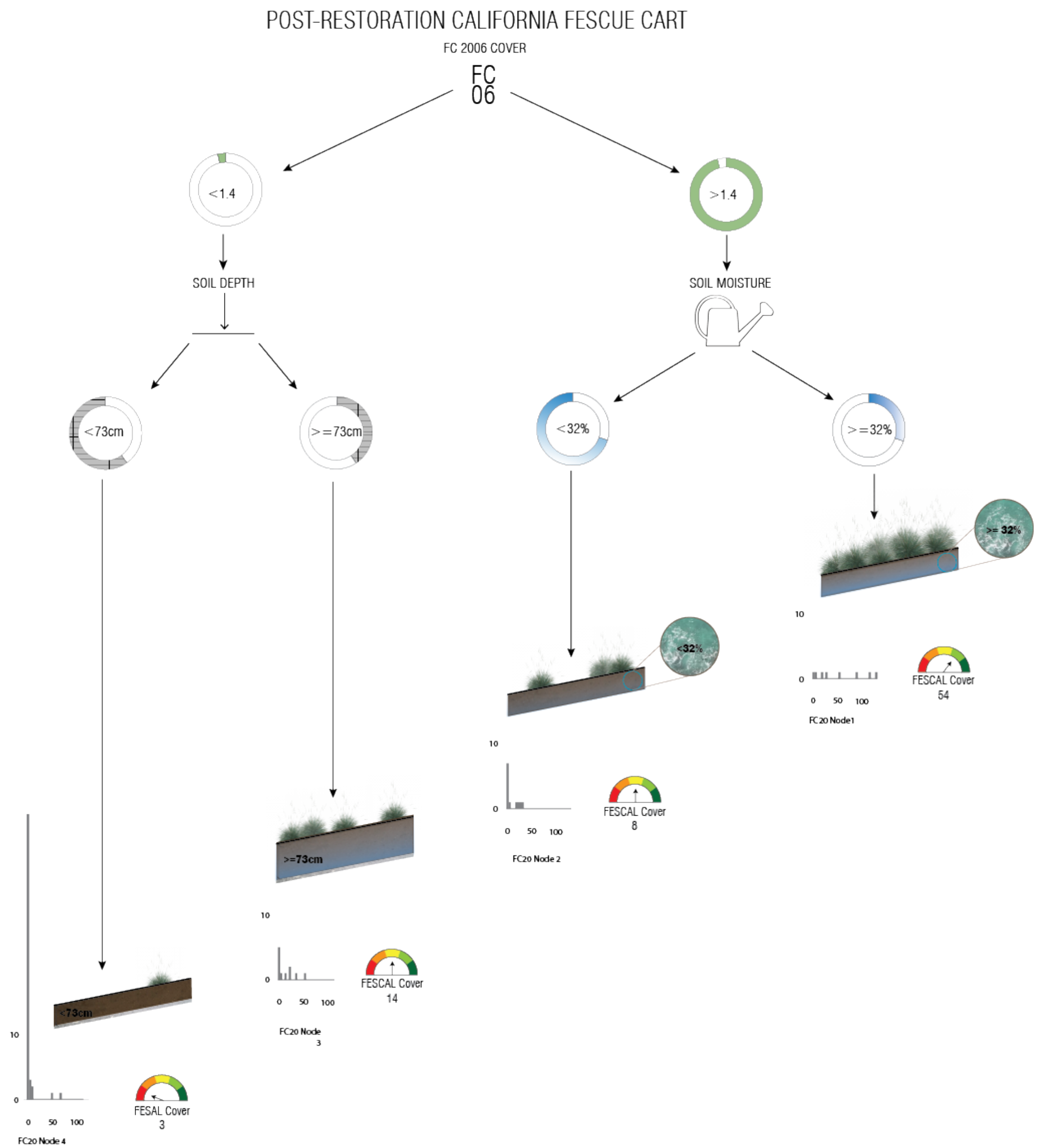


***Figure 1.6:* Post-restoration *Festuca californica* CART**. *When present in higher numbers pre-restoration, F. californica made the most gains in areas with higher overall moisture. When absent or barely present, soil depth determines F. californica's ability to spread. Histograms indicate node distribution. This Illustration is an interpretation of the results. Each leaf/node of the CART is accompanied by a graphical representation of the landscape, variable value, distribution of plot values and a dial showing the outcome for the dependent variable.Original CART output in Appendix S Figure 1.5.*

Festuca californica vs Festuca roemeri.

Initial Data Exploration. Scatterplots indicated that in both pre and post restoration, *F. californica* and *F. roemeri* PI cover have an inverse relationship.

CART (PI data). The 2020 *Festuca roemeri* vs. *Festuca californica* CART (Figure 1.7) delineates where each target species was able to expand or establish in comparison to one another (r^2 = .28). To compare the effects of natural regeneration only, no seeded plots were included in this analysis. Not surprisingly, the CART indicates that pre-restoration presence/cover is key to 2020 success for both species. If *F. roemeri* was present pre-restoration, it always succeeded over *F. californica* (*F. roemeri* outperformed by an average of PI cover of 10%) and vice versa. *Festuca californica* was most successful in outperforming *F. roemeri* when pre-restoration cover was higher than 1.4% (*F. californica* outperformed by an average of 23%). A third split identifies that when not or barely present, *F. californica* success depends on soil depth and was more likely to establish or spread if soil depth was above 70 cm (mean = 11%). Below that threshold, *F. californica* did not do as well (mean = 4%).

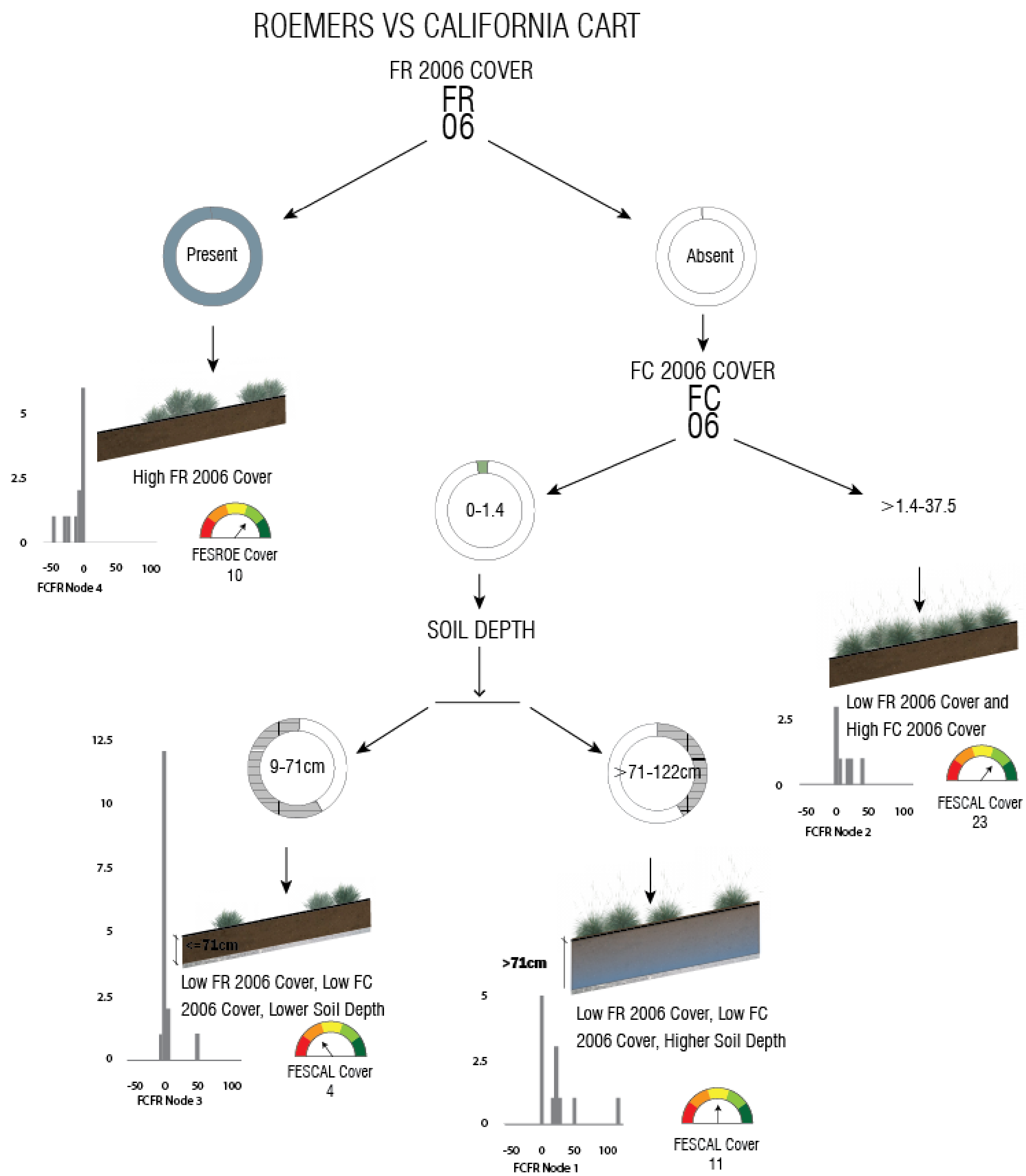


***Figure 1.7:* Post-restoration *Festuca roemeri vs. Festuca californica CART*.** *Festuca roemeri and F. californica should be seeded in areas they are observed to be present. For F. californica, soil depth determines growth if little F. californica cover is observed. Each leaf/node of the CART is accompanied by a graphical representation of the landscape, variable value, distribution of plot values and a dial showing the outcome for the dependent variable. Original CART output in Appendix S Figure 1.6.*

DISCUSSION

In what types of biophysical and climatic microenvironments did each target species perform best?

I next synthesize across pre-restoration and post restoration results, including plot-level change, to describe the microenvironments that appear to best support each species. I use the terms "perform" and "outperform" to indicate the relative success of each species (in most cases their cover or biomass) to distinguish metrics of success from the mechanisms behind them, such as environmental tolerances versus competition, which I can only infer.

Festuca roemeri performed best in xeric, low productivity soils with limited canopy cover. Before restoration, it did best in open-canopied prairie and savanna cover types, all of which were xeric sites that had resisted successional infill. It was rarely present in areas where successional infill had created closed-canopy woodland or forest. Post-restoration it did best in areas where it had high pre-restoration cover, nearly all of which were xeric meadows. Where it was present with low cover pre-restoration, it was most successful in areas with shallow soil, which also tended to be droughty.

In contrast, *F. californica* performed best in moist, deep, fertile soils with low to moderate canopy cover. Before restoration, it did best in areas with silty, deep soils, which are expected to be more productive, and better able to retain plant-available soil moisture (Xu, 2021; Hillel & Hatfield, 2005; Yang et al., 2016). Soils above the CART silt threshold of 46% were all silt loams, which have high water storage capacity (Klocke & Hergert, 1990). *Festuca californica* was almost never found in open-canopied, xeric meadows before or after restoration but was able to tolerate high canopy cover in more mesic sites as scattered, suppressed individuals. When soil moisture data was collected in 2021, deeper soils and higher soil moisture emerged as the key factors predicting *F. californica's* post-restoration success.

My evidence suggests that *F. californica* is the competitive dominant in mesic, productive, open-canopied areas, while *F. roemeri* is the dominant species in xeric, stressful, sites with little to no tree canopy. It thus appears that the distinctive life history strategies of each species led them to perform best in very different environmental conditions. This leads to a partitioning of the site into different zones of expected dominance with some overlap in zones of intermediate environmental stress where *F. roemeri* is able to tolerate the competition and *F. californica* is able to tolerate the moisture limitations of summer drought.

To what degree was natural regeneration versus seeding important to each species' recovery post-restoration?

A decade post-restoration, neither bunchgrass was able to effectively colonize sites where they were not present pre-restoration without seeding, despite the creation of suitable habitat.

Because of its shade intolerance, *F. roemeri* was excluded from areas with extensive canopy cover prior to restoration but did exceptionally well when seeded after thinning was complete. In the seeded plots, the combined cover of *F. roemeri* and *S. arundinaceus* increased 22-fold over unseeded plots to comprise an average of 41% of all cover in these plots. *Festuca roemeri* outperformed *S. arundinaceus* in the majority of these plots, with nearly double the percent cover of *S. arundinaceus* on average. It performed well in both the xeric, stressful sites where it was found prior to canopy reduction and in the areas of intermediate soil moisture and productivity. In these intermediate conditions it produced large plants with high seed production. However, it appeared to be outcompeted by either *S. arundinaceus* or *F. californica* when these sites became too productive.

Of particular importance, seeding *F. roemeri* reduced average introduced annual grass cover 10-years post-restoration by 54% compared to similar areas without seeding. At the level of individual plots, *F. roemeri* was more than 20-times more likely to outperform introduced annual grasses in seeded plots than in unseeded plots. Seeded *F. roemeri* most consistently outperformed annual grasses in thinned plots with intermediate soil moisture and depth which facilitated successional infill prior to restoration. Once annual grasses colonized these previously forested sites, they were able to multiply rapidly, establishing dense cover and abundant seed production. However, because *F. roemeri* can tolerate less productive sites than other perennial species, *F. roemeri* was able to dominate these intermediate zones when seeded. Seeding dominant native bunchgrasses with similar tolerances as *F. roemeri* should thus be a priority following canopy reduction to help them colonize suitable unoccupied areas and to preempt potential invasive species.

Given that climate change will alter the current status of many site-level characteristics (soil moisture, temperature, etc.) and may increase grassland invasibility, management must be proactive. Higher temperatures and reduced soil moisture associated with climate change in Western Oregon appear to advantage introduced annual grasses over native perennial grasses (Ziska, 2011; Bachelet et al., 2011; Pfeifer-Meister et al., 2016; Reed, 2021). Disturbance events associated with climate change, such as increased wildfires, are also likely to benefit introduced annual grasses (Brambila et al., 2021) When seeded *F. roemeri*'s ability to outperform the other two perennial grasses in low-moisture environments, and the introduced annual grasses in intermediate environments, suggests that it may have a stronger tolerance to climate-change induced drought in xeric zones and subsequently be able to resist site takeover by introduced annual grasses. Additionally, it seems likely that some intermediate sites which are currently best suited to *F. californica* may transition to xeric conditions under a future climate, making them more vulnerable to invasive annual grasses and thus more appropriate for *F. roemeri*.

In previously forested areas where *F. californica* was present but suppressed, it was able to increase cover substantially following thinning without seeding. *Festuca californica* was dominant or co-dominant in 1/3rd of the seeded plots where it was present pre-restoration, despite not being seeded itself. It is notable that these results show that *F. californica* may be able to outcompete the highly invasive pasture grass *S. arundinaceus* in productive areas, suggesting that it could hold its own against this and other introduced perennial grasses in the right situations. However, even after thinning, it only colonized about 10% of plots where it was not previously located. Although we don't have results for *F. californica* seeding due the seed collection mix-up, given its ability to increase when present in plots, and the similarities of its life history to *S. arundinaceus*, I expect that with seeding it would colonize and establish successfully, just as the other two perennial grasses did.

Identifying the locations where different plant species are most likely to succeed over the long-term can strengthen and streamline grassland restoration management. This is especially important when considering keystone species such as the dominant bunchgrasses. Although protocols for wild seed collection followed by bulk production in agronomic settings has dramatically increased the availability of native seed, production still lags behind demand, and a strategy of "let the plants sort themselves out" can be wasteful and costly. Particularly in heterogenous landscapes, applying a homogeneous management plan is likely to use resources inefficiently.

Instead, restoration management should consider life history strategies and target seeding activity based on where each species is expected to succeed.

What generalizable lessons can be gleaned from matching species' life history and appropriate biotic, physiographic and climatic characteristics when creating a regional ecotope-based management?

How might we begin to generalize from the process of identifying the appropriate ecotopes of a small number of target species based on their life history strategies to that of matching a set of site ecotopes with larger suites of plant species? Grime's (1977) CSR (competitor - stress tolerator – ruderal) system for describing basic plant life history strategies in relation to environmental gradients offers a potential way forward. The CSR strategy posits that plant species can be classified as competitors, stress tolerators, or ruderal species based on life history strategies that predispose them to be successful in different types of environments. *Competitors* perform best in relatively stable, productive environments via suites of traits that allow them to preempt available resources from other plants in these locations; *stress tolerators* perform best in variable and resource-poor environments via traits that protect them from stressful conditions that are difficult for other plants to endure; and *ruderal species* perform best in environments characterized by intense disturbances that set back or kill other plants by investing in producing abundant propagules that can disperse rapidly to exploit the available space and resources of recently disturbed sites (Pierce et al. 2017).Because each species must allocate limited resources toward the traits that allow them to succeed in a particular biophysical environment and associated disturbance regime, they can't succeed in all situations, that is, their genetics predispose them toward performing well in a certain type of environment. For example, stress tolerators are usually poor competitors in more moderate environments. I propose that this categorization system could be used to begin to match much larger suites of species to appropriate ecotopes.

For example, the grass species assessed at Jim's Creek fit the CSR system well and follow a consistent pattern that can be used to infer potential appropriate ecotopes (Table 1.5). *Festuca roemeri* is a stress tolerator that can establish substantial cover and produce abundant seed in challenging sites where competition is low. In contrast, *F. californica* and *S. arundinaceus* are competitors that respond well to mesic, productive sites, but perform poorly in the xeric sites to which *F. roemeri* is well adapted. The introduced annual grasses found at Jim's Creek can be described as both ruderal and stress tolerator species. Like *F. roemeri,* they can grow and reproduce in xeric, less productive sites, but they have the added benefit of rapid colonization post-restoration, particularly in the absence of seeding dominant native species.

Table 1.5: Target Species in the CSR Category System. *Festuca roemeri fits the description of Stress Tolerator, F. californica and S. arundinaceus are Competitors, and the introduced annuals are Ruderal Stress Tolerator species.*

Species	Grimes CSR type	Life History Characteristics
F. roemeri	Stress Tolerator	Tolerates xeric sites characterized by low summer soil moisture, high temperatures and shallow soils; shade intolerant.
F. californica	Competitor	Grows and reproduces well in mesic, productive soils, tolerates semi-shade.
S. arundinaceus	Competitor	Grows and reproduces well in mesic, productive soils; relatively low shade tolerance.
Introduced annual grasses*	Ruderal Stress Tolerators	Able to quickly colonize intensively disturbed sites rapidly by producing large numbers of propagules that disperse and establish quickly. Annual life cycle enables them to increase numbers rapidly. Because they complete their full life cycle early in the growing season before soil moisture is exhausted, they can also persist on stressful sites.

By similarly categorizing more potential grassland target species in this system suites of species can be identified and matched to appropriate site ecotopes.

CONCLUSIONS

These results can be best understood in a broader framework of targeting key grassland species toward the physical environments and community structures, or ecotopes, in which they are likely to perform best for efficient, successful restoration in both the short and long-term. The spatial patterns of forest succession at Jim's Creek reveal underlying resource gradients that controlled the processes and outcomes of forest succession. These same resource gradients underlie the relative success of the different bunchgrasses that managers want to reintroduce into restored areas. In this light, it is clear that the long-standing resource gradients and associated edaphic features of the site delineate a functional set of ecotopes that can help define long-term management units under a variety of desired future conditions.

Within the areas of successional infill, I have identified two ecotopes related to native bunchgrass performance: zones of intermediate to low soil depth and soil moisture where *F. roemeri* performs best and deeper productive soils where *F. californica* performs best. These two bunchgrasses have substantially different ecotopes that bracket the full range of site variability, making them the bookends of grassland restoration on site. In other words, these two ecotopes are not a simple dichotomy, but an indication of the range of conditions at Jim's Creek, and between the two there is a gradient of conditions within which species may co-dominate or experience shifts of suitability under climate change.

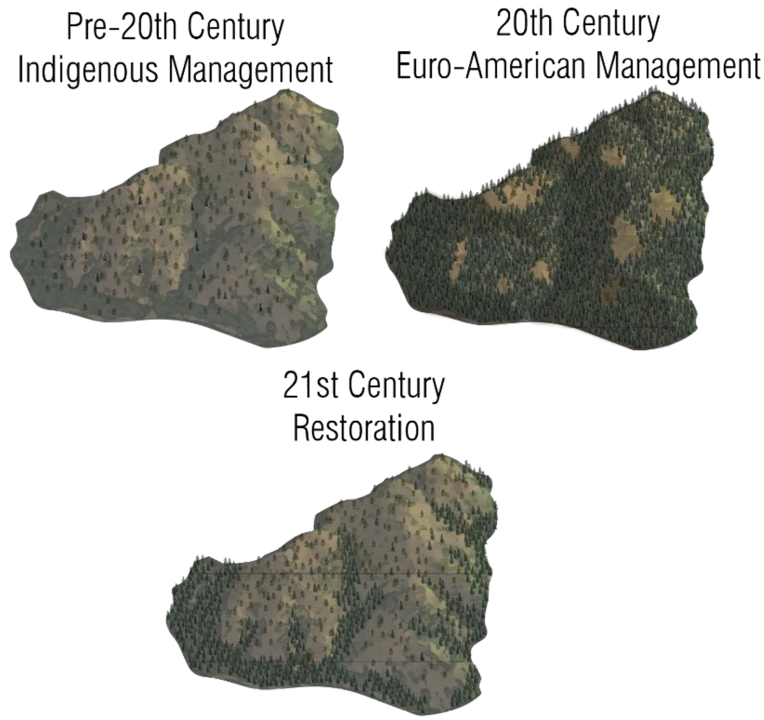
Although perennial native bunchgrasses are often considered to be a single functional group, the different life history strategies of these species require a varied approach. Seed mixes need to be tailored to the specific requirements and tolerance of each suite of species to avoid inefficiency and foster seeding success. Grimes CSR system provides a framework of categorization that can be used alongside identified ecotopes to manage bunchgrass species more efficiently and successfully in a restored grassland,

and better support native species recovery on site. For efficient, effective restoration on large, heterogenous sites, I recommend management plans use this methodology to target suites of species to areas where they can be expected to establish and persist in the face of interspecies competition, annual climatic extremes, and future climate trends.

The following handbook presented in Chapter II is intended as a graphic guide of the methods, results, and some of the discussion reported in Chapter I.

RESTORING HISTORIC GRASSLAND LANDSCAPES

IN THE OREGON CENTRAL CASCADES



After Euro-American colonizers settled the region, the United States Forest Service enacted fire suppression policies to support timber management in the early 20th century, resulting in many prior grassland and savanna environments in the Western Cascades giving way to forest succession (Winkler, 2005, Boyd, 1999). Today, multiple grassland restoration projects are underway in Oregon, attempting to mediate the loss of habitat.

In this project, I analyzed the performance of two native bunch grass species in a restoration area in the central Cascades. Using data visualization, linear regression, categorical and regression trees, and field observations, I identified factors that influence each species success, and made recommendations for a seeding strategy on site. These findings have direct implications for the study site, but can also be applied in other restoration sites in the greater region.

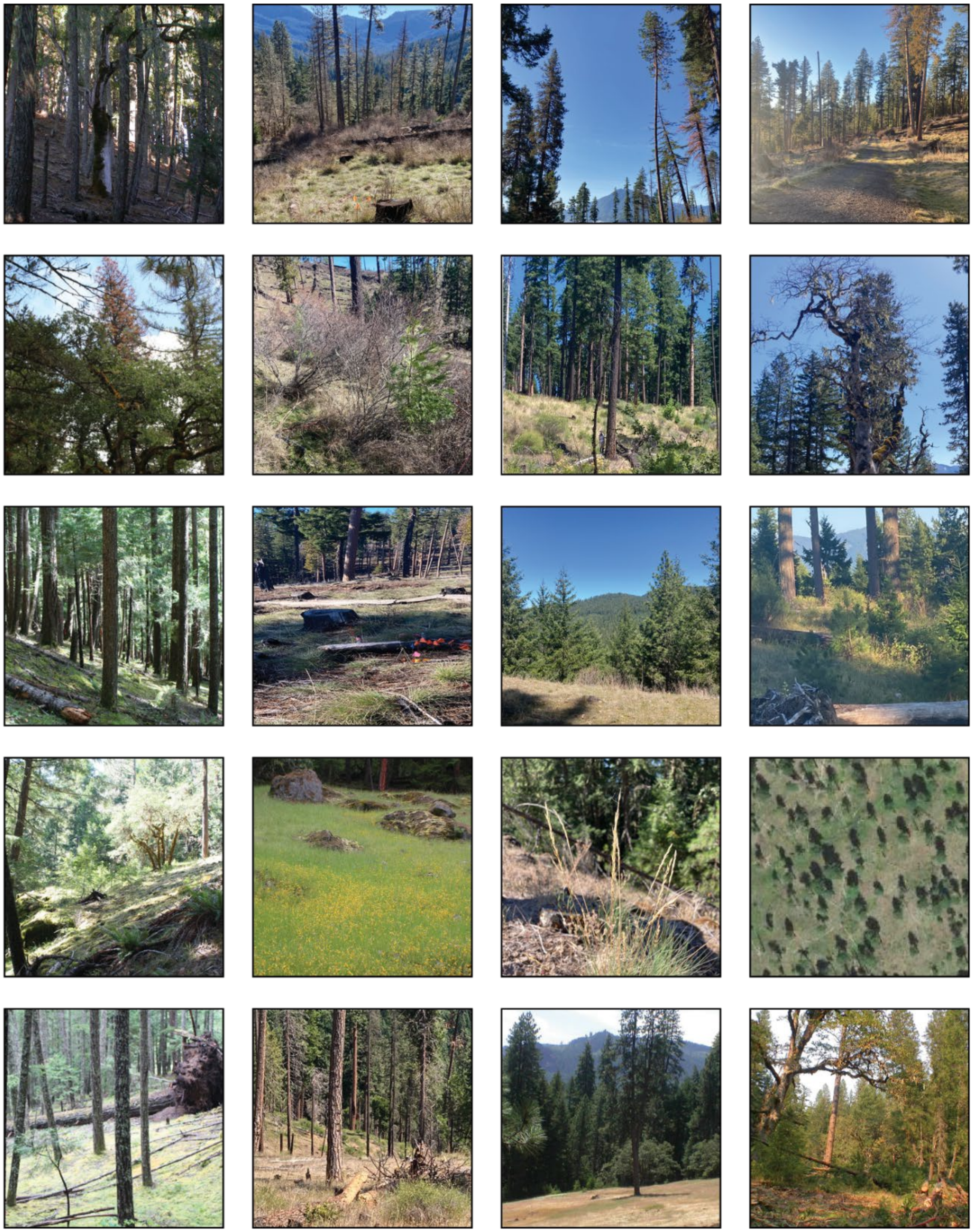
WHY MAKE A HANDBOOK ANYWAY?
MAKING SCIENTIFIC RESEARCH ACCESSIBLE

I came to ecology through the back door. Though I spent time as a young girl fascinated by science, I felt too intimidated to engage fully with the field. In the community I was raised in, young girls were not encouraged to focus on science or math. As an undergraduate, I pursued environmental studies, but again was too fearful of courses in hard sciences to be an environmental scientist. I was certain that they would just be too difficult, that I didn't have what it took to succeed in the field.

But the thing about curiosity is that it doesn't die easily, so when the opportunity arose to become involved in the ongoing research work at the Jim's Creek Restoration Area as a master's student, I jumped for it. I quickly remembered all of the reasons why scientific research had intimidated me as a kid, suddenly sifting through dense articles citing methods and statistics I'd never heard of.

Now, after a metaphorical trial by fire, I'm finally confident in my ability to engage in scientific discourse. This handbook is my attempt to avoid creating yet another inaccessible scientific paper, the same thing that discouraged me for so many years. As a student of Landscape Architecture, I've been trained to boil complexity into a quickly graspable graphic language. In this handbook, I sought to use that training to bridge the divide between scientific research findings and those who are not trained to navigate scientific literature. Grassland restoration, like a lot of ecological ventures, is tough. In my opinion, there's no need to make it tougher. My goal in creating this handbook was to make these findings accessible to a wider audience and invite more people into the scientific process.

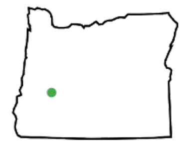
Through the experience of completing this project and creating the handbook, I found that there is definitely an underutilized role for Landscape Architects in the science communication. It is not so far removed from what we do already, but it has an important power to make not only scientific findings but also the subject as a whole more accessible. If we create alternative avenues for understanding, more people can feel confident in engaging with scientific discourse, and more people can feed a curiosity that may have been stifled for years. But most importantly, perhaps, a more diverse array of ideas could be included in the dialogue for ecological thought, which could get us closer to a deeper understanding of the world around us.

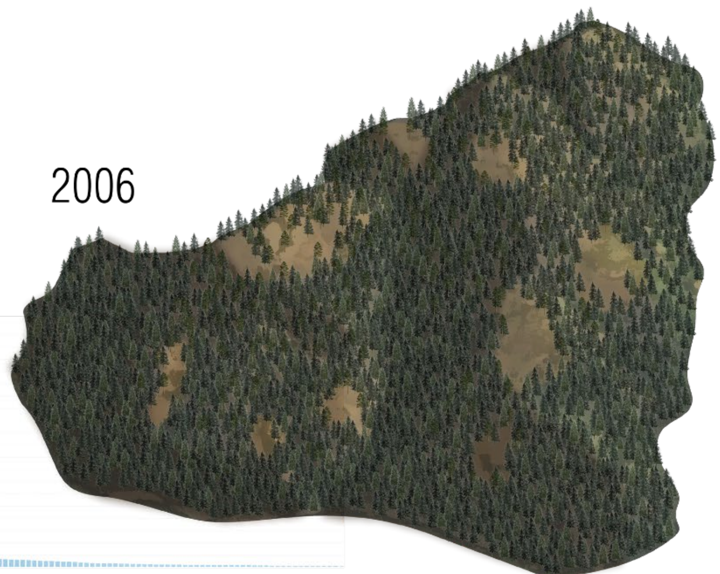


SITE DETAILS

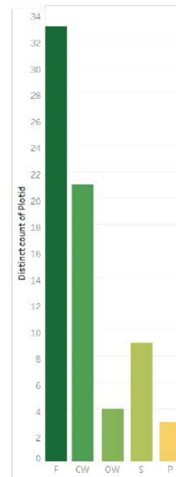
WHAT IS THE JIM'S CREEK RESTORATION AREA?

For the past decade, the U.S. Forest Service (USFS) has managed the Jim's Creek Restoration Area (JCRA), a predominantly south- to southwest-facing 258-hectare site in the mid-elevations of the western Cascades, with the intent to restore it to an oak-pine savanna landscape.



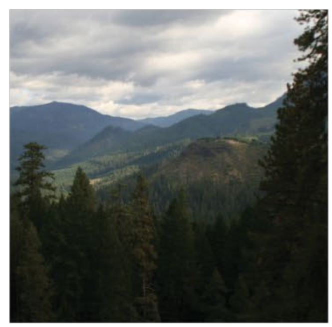


Ground layer Cover 2006
Low Ground cover prior to restoration



2006 Community Types
Prairie = p
Savanna = s
Open Woodland = ow
Closed Woodland = cw
Forest = f





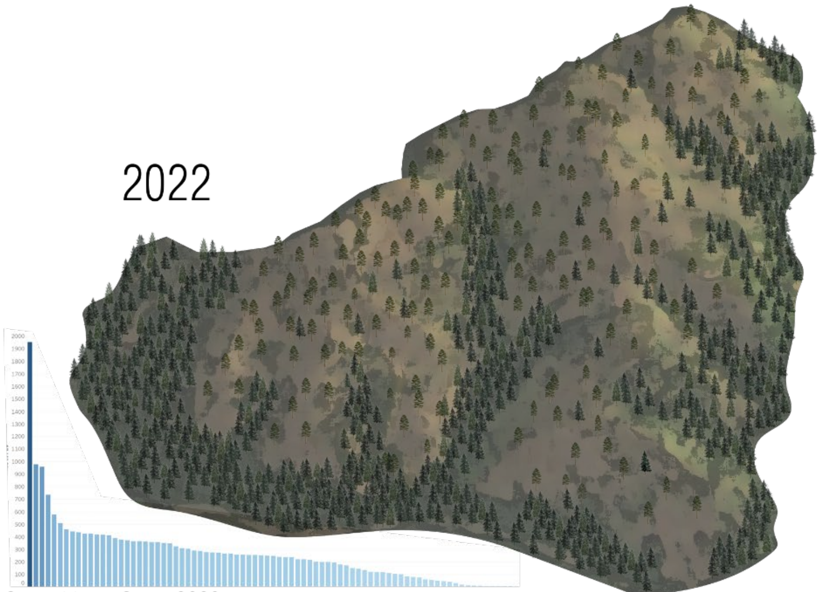
TIMELINE

The JCRA has a longer past than just the U.S.F.S restoration activity. This site used to be managed as an oak-savanna by indigenous peoples prior to Euro-American colonization. The loss of this critical habitat is part of why restoration projects like this are so important.

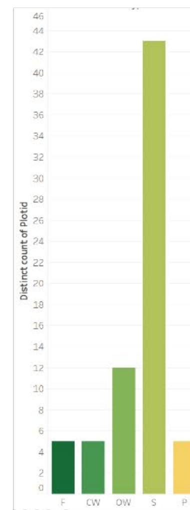
Prior to 1860
for hundreds and potentially thousands of years indigenous peoples manage Jim's Creek through cultural burning, supporting oak-pine savanna

1860s
Euro-American colonization and removal of indigenous peoples

To restore the site, ~90% of the small, dense trees were cut, retaining any old growth trees. By the end of the thinning, about 30% of the canopy cover had been cut back. After restoration, the majority of the JCRA transitioned from forest cover to oak-pine savanna, and ground layer cover increased by an average 16-fold



Ground layer Cover 2020
Ground cover increases after restoration



2020 Community Types

1920s
U.S. Forest Service enacts fire suppression policy

2006-2010
U.S.F.S. Tree thinning restoration activity begins

RESEARCH INTRODUCTION

TARGET SPECIES

I chose two native perennial bunch grasses on site to assess their progress in re-vegetating the site after restoration

Festuca roemeri

Festuca californica

Roemers fescue is a compact bunch grass native to Oregon with a slow growth rate and moderate life span. It can grow to 3' tall at its mature height. It is tolerant of drought conditions and poor soils.

California fescue is a bunch grass native to Oregon with a moderate growth rate and moderate life span. It can grow to 4' tall at its mature height. It has deep roots and drought tolerance.

METHODS

I wanted to translate what I found about these species into a more accessible format for those who don't have a scientific or statistical background. I collected field data on moisture and temperature and species biomass and drew on data collected in the past to run tests of regression and Categorical and Regression Tree Analysis (CARTS). I used a graphic language to make these findings easier to understand and interpret.

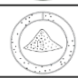
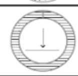
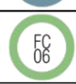
Site Data and Observations

Statistics

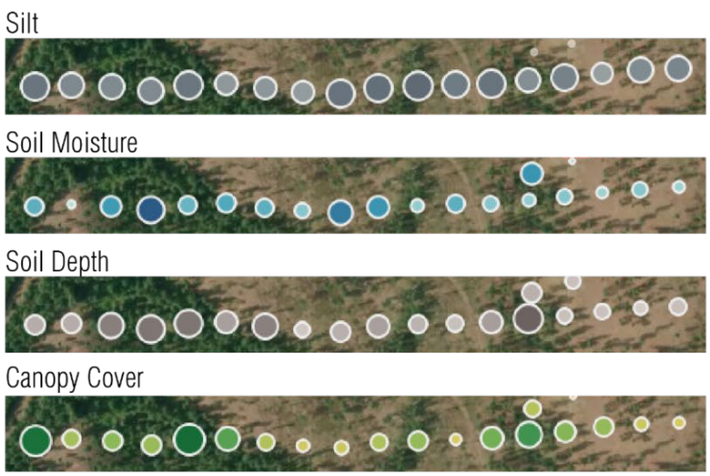
Accessible Graphics of Findings

VARIABLES

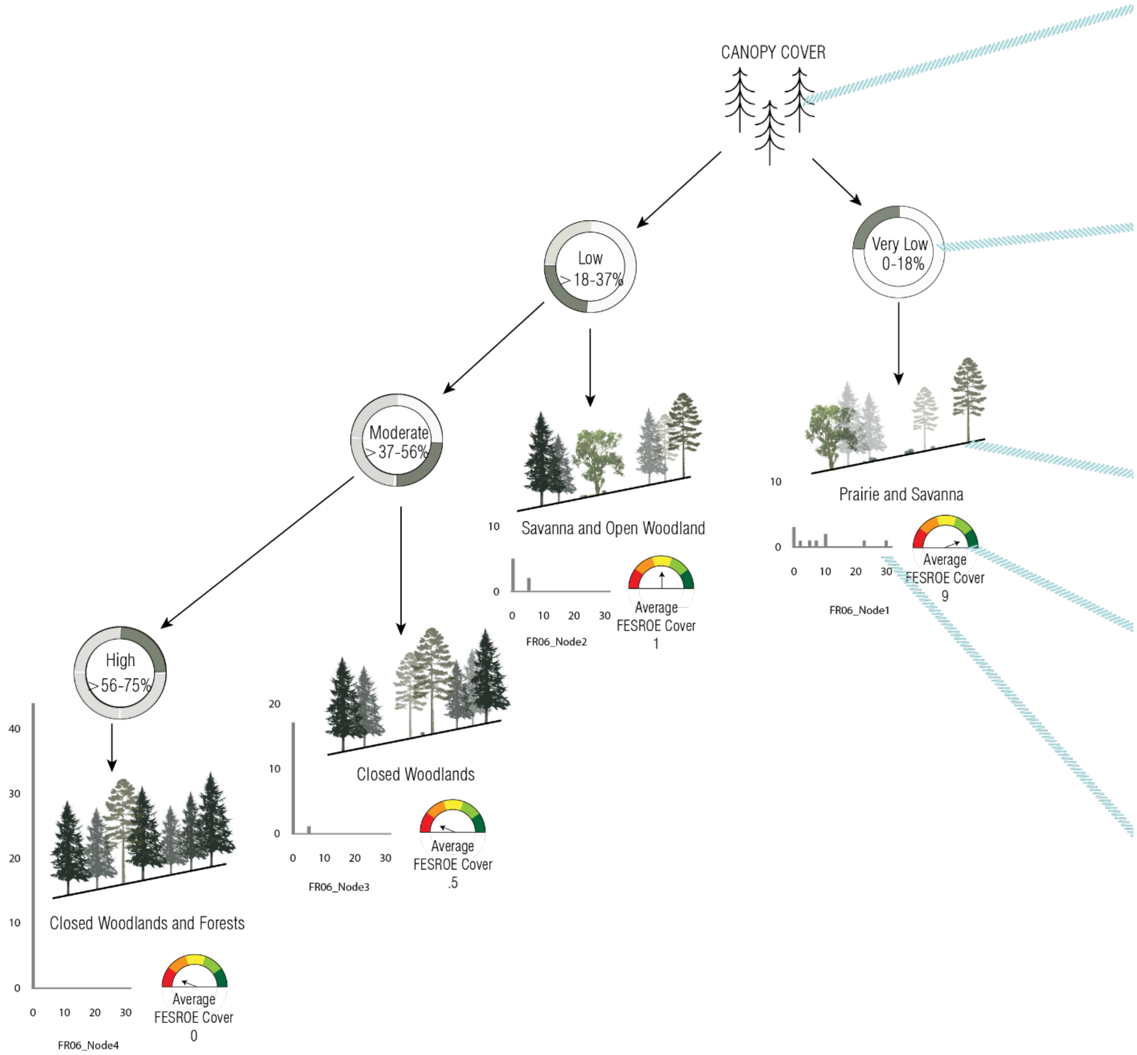
Between the data I collected in the field and the data collected previously by other researchers, I had a lot of information to sort through to find what variables were important to my target species. After a lot of analysis, the following variables came to the forefront as the key players in target species success.

Symbology	*Variable*	*Description*	*Range*	*Average*
	Canopy Cover	Approximate canopy cover recorded in the field pre- and post-restoration	0-75%	22% (50% Pre-Restoration)
	Soil SIlt % Content	Percent silt in soil recorded in the field in 2008.	27-53%	40%
	Soil Depth	Average soil depth of five measures taken at each plot in 2008.	10-122cm	48cm
	Relative Soil Moisture	2021 field measured relative soil moisture. Divided into summer and full season.	25-47%	32%
	Minimum Temperatures	2021 field measured average minimum temperatures by plot.	8-11 C	9 C
	FESROE 2006 Cover	2006 field measured cover estimates using the point intercept method.	0-30	1.3
	FESCAL 2006 Cover	2006 field measured cover estimates using the point intercept method.	0-37.5	2.04
	Seeded	Indicates whether a plot was seeded with FESROE and SCHARU.	yes/no	20/82 plots seeded

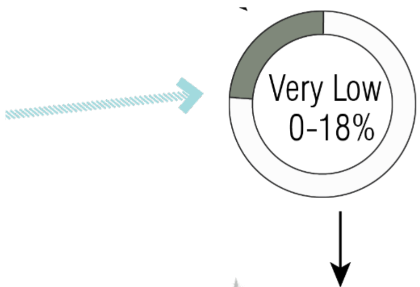
Ecological research is complex. Our variables generally follow a gradient spatially and are not random. These patterns are not easily picked up by statistical analysis. The images below show these spatial relationships on one of our transects. Larger circles and darker colors indicate higher values of each variable. These spatial relationships are important to remember when interpreting results



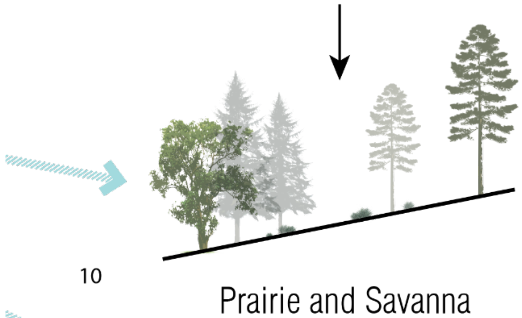
RESEARCH INTRODUCTION
HOW TO READ A CART



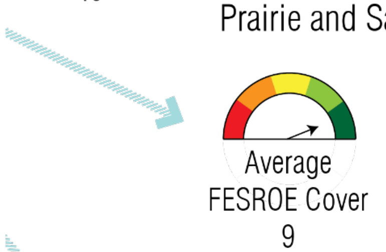
- What variables are we using to split the data?



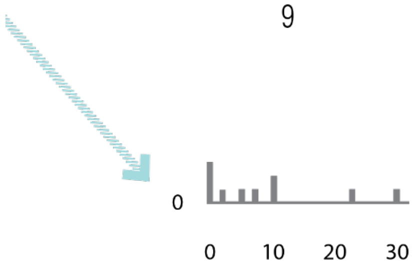
- What's the split's threshold, and where is it in the larger range we see on the site?



- What does that look like? How would we describe it?



- What's the distribution average, and is it a relativity high, low, or moderate value?



- What's the distribution of data in this leaf?

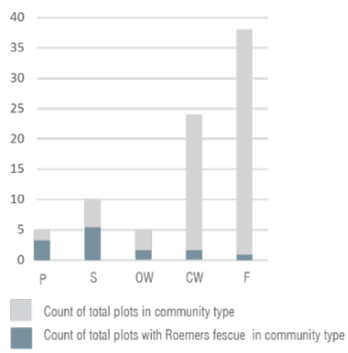
ROEMERS FESCUE

FESTUCA ROEMERI

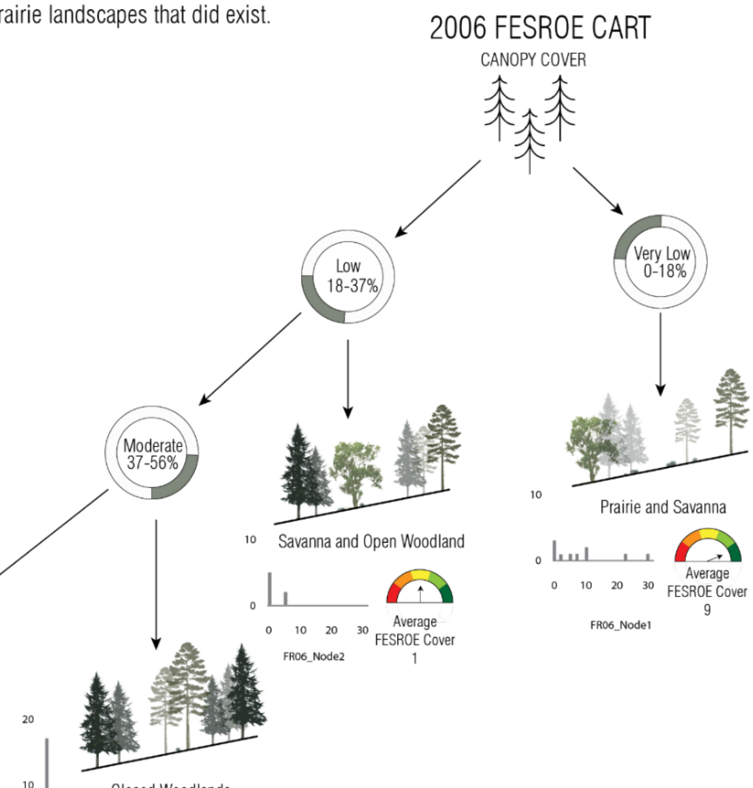
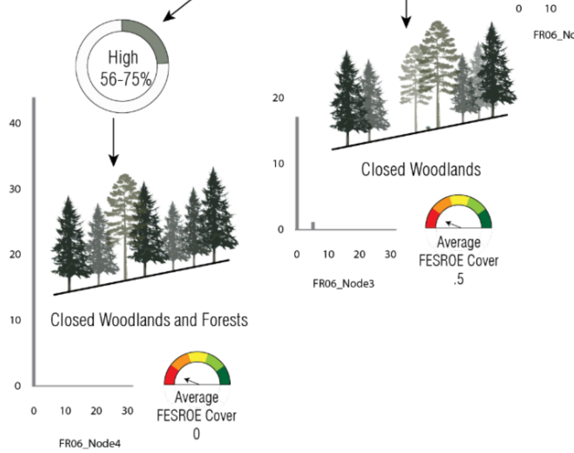
WHERE WAS IT PRIOR TO RESTORATION?

Before restoration, Roemers fescue was dependent on areas of low canopy cover. These prairie and savanna landscapes were rare, making up a small percentage of plots, but Roemers fescue inhabited the majority of savanna and prairie landscapes that did exist.

2006 Roemers fescue presence in plot by community type



Prairie = p
Savanna = s
Open Woodland = ow
Closed Woodland = cw
Forest = f

A pre-restoration meadow at the JCRA. Photo taken in 2006. These meadows were often areas of shallow, poor soils where dense trees couldn't establish

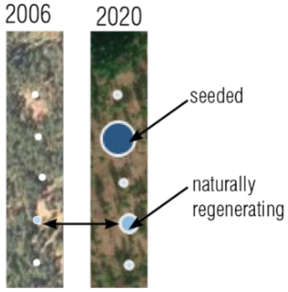
ROEMERS FESCUE

FESTUCA ROEMERI

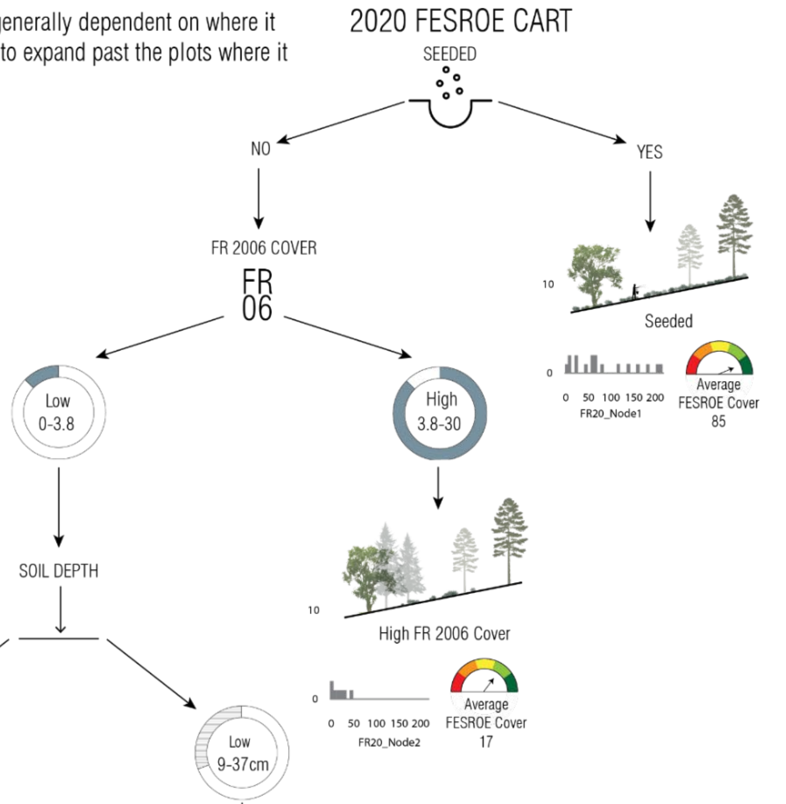
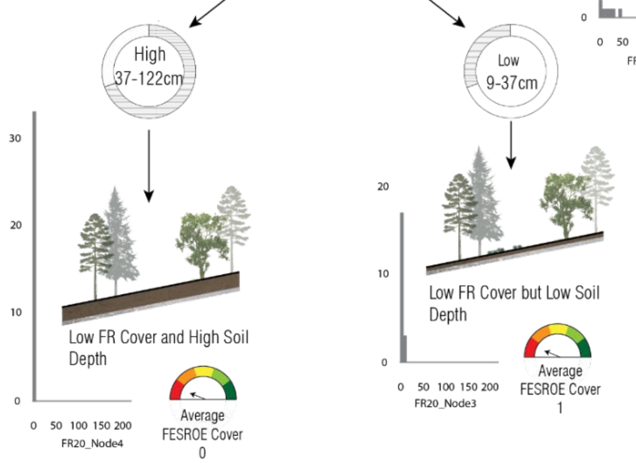
WHERE IS IT AFTER RESTORATION?

After restoration, Roemers fescue was seeded in 20 plots, where it generally did quite well.

If not seeded, Roemers fescue was generally dependent on where it had been previously, usually unable to expand past the plots where it had already existed.



The above image shows 2006 and 2020 Roemers fescue cover. The color saturation and the size of the circle both represent the amount of Roemers fescue observed on site.

Roemers fescue in a seeded plot

When Roemers fescue was seeded but not present in 2006, soil depth determined how successful it could be. Lower soil depth is associated with higher Roemers fescue success and vice versa. This likely has to do with competition. Sites with deeper soils are more suitable for most ground layer species. Because Roemers fescue is tolerant of sites with poor soils and limited moisture, it can withstand sites with shallower soils and avoid being out-competed in more productive sites.

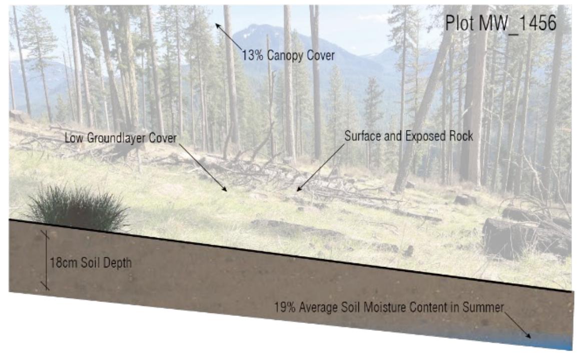
ROEMERS FESCUE
FESTUCA ROEMERI

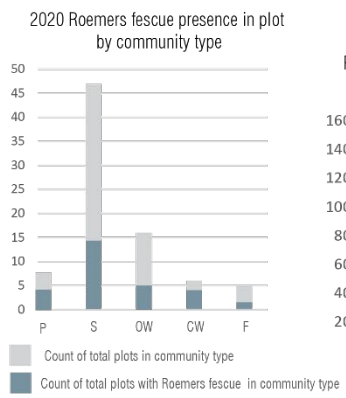
SEEDING EXPERIMENT

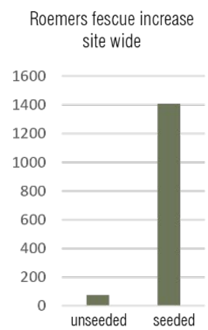
The majority of the site became appropriate for Roemers fescue after the restoration, but Roemers fescue wasn't able to spread beyond the plots it was in in 2006 without being seeded.

Roemers fescue needs to be seeded in a restoration area if it is going to succeed.

Suitable habitat for Roemers fescue but not seeded
Little increase after restoration

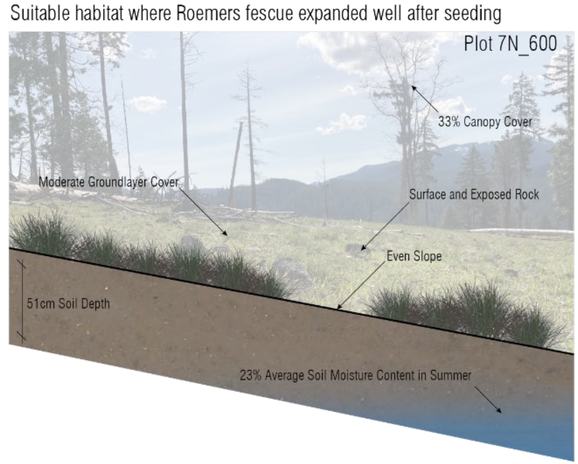






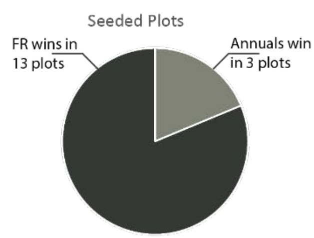
Prairie = p
Savanna = s
Open Woodland = ow
Closed Woodland = cw
Forest = f

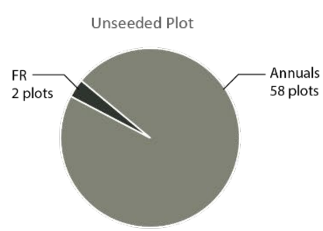
Suitable habitat where Roemers fescue expanded well after seeding



INTRODUCED ANNUAL GRASSES

Roemers fescue's unique ability to handle extremely dry environments make it a key strategy species in outperforming introduced annual grasses. At Jim's Creek, Roemers fescue was able to outperform introduced annual grasses the majority of the time when seeded. The pie graphs to the right show the difference seeding made in the number of plots in which Roemers Fescue (FR) outperformed the introduced annual grasses (Annuals).





Oregon's climate is expected to undergo changes in the future. Climate projections indicate an increase of precipitation in the rainy season and drier, hotter summers. Though this change is likely to benefit grassland ecosystems as a whole, introduced grass species are expected to see the greatest benefit. Because of it's tolerance for low moisture, Roemers fescue may be a key piece of invasive annual grass management in the future.

ROEMERS FESCUE
FESTUCA ROEMERI

INTRODUCED INVASIVE TALL FESCUE

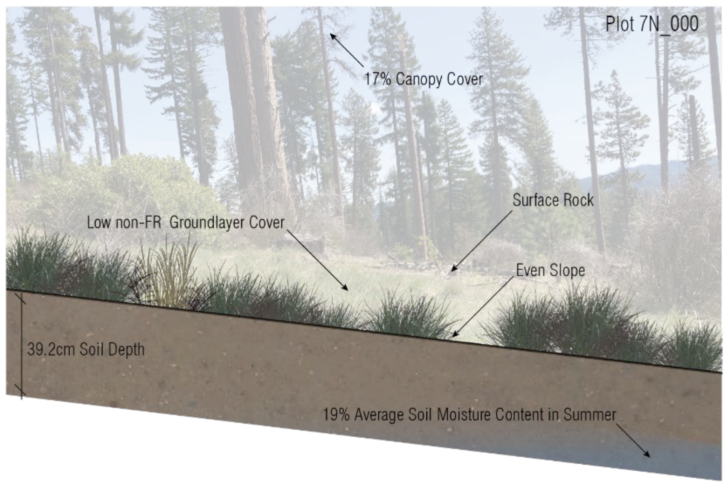
The seeded plots were not only seeded with Roemers fescue. The U.S. Forest Service mistakenly seeded these plots with an introduced tall fescue, Schedonorus arundinaceus, as well. I looked at what environmental factors determine whether Roemers fescue was able to outperform the tall fescue.

Roemers fescue was able to outperform the tall fescue when soil moisture was low. Low minimum temperatures also increase Roemers fescue success. This likely relates to site exposure since canopy cover insulates against heat loss at night. However, soil moisture is the most important variable.

Best Roemers fescue Success

Visible
- Low non-Roemers fescue ground layer cover
- Surface rock present
- Even slope that doesn't have areas where runoff can collect
- Low canopy cover

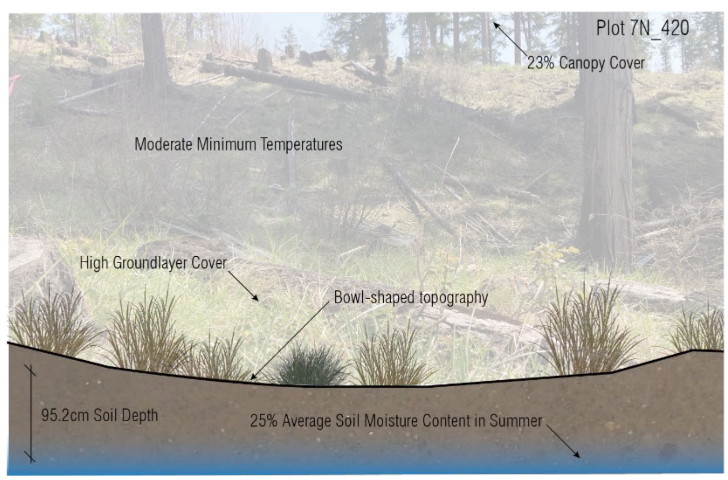
Invisible
- Shallow soil depth
- Low summer season soil moisture



Worst Roemers fescue Success

Visible
- Higher canopy cover
- Topography which creates moisture collection opportunities
- High ground layer cover

Invisible
- Highest summer season soil moisture of any seeded plot
- Deep soils
- Warmer minimum temperatures (more canopy cover insulation)



CALIFORNIA FESCUE

FESTUCA CALIFORNICA

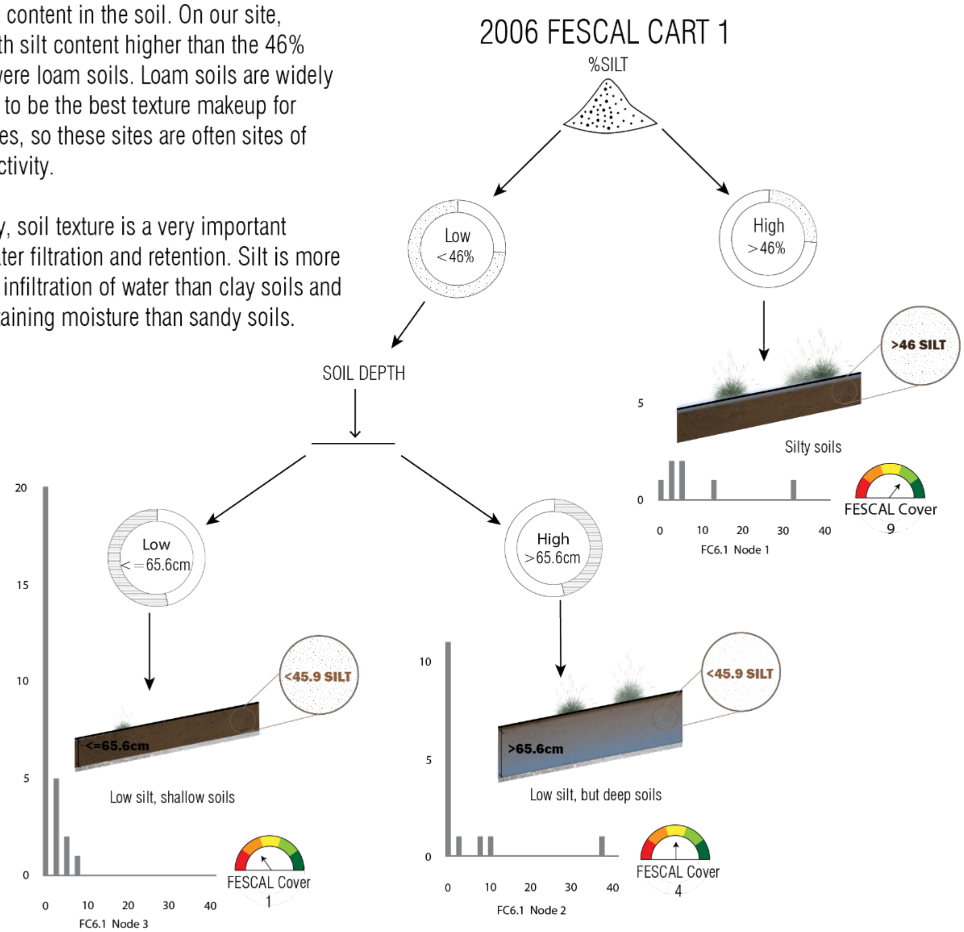
WHERE WAS IT PRIOR TO RESTORATION? CART MODEL 1

All models are wrong, some are useful. ~ George E.P. Box

Trying to understand why California fescue established where it did prior to restoration through CARTs was complicated. CARTs, like all statistics, seek to represent the reality of what is happening, but they invariably represent some things wrong. To try to get a more holistic picture of 2006 California fescue's patterns, I identified two Models to try to visualize what was important.

In both Models, California fescue responded most to silt content in the soil. On our site, all plots with silt content higher than the 46% threshold were loam soils. Loam soils are widely considered to be the best texture makeup for most species, so these sites are often sites of high productivity.

Additionally, soil texture is a very important piece of water filtration and retention. Silt is more effective in infiltration of water than clay soils and better at retaining moisture than sandy soils.



The second split in this Model indicates that when the site has a lower silt content, California fescue may still succeed if the soil depth is more than 65cm. Deeper soils are more capable of retaining moisture in drought conditions. Because California fescue has such deep roots, it is able to access water held in these deep soils.

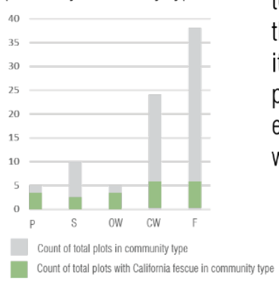
CALIFORNIA FESCUE

FESTUCA CALIFORNICA

WHERE WAS IT PRIOR TO RESTORATION? CART MODEL 2

In this Model, California fescue again follows the same pattern regarding silt content, but the second split in the data is based on canopy cover. Above 45% canopy cover is associated with lower California fescue success. This makes sense when you consider how much California fescue was able to expand after canopy thinning. Higher canopy appears to control some of California fescue's ability to succeed.

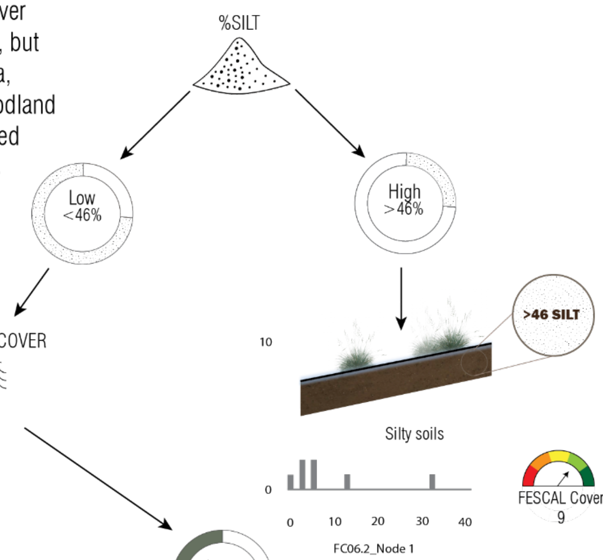
2006 Plots with California fescal present by Community Type

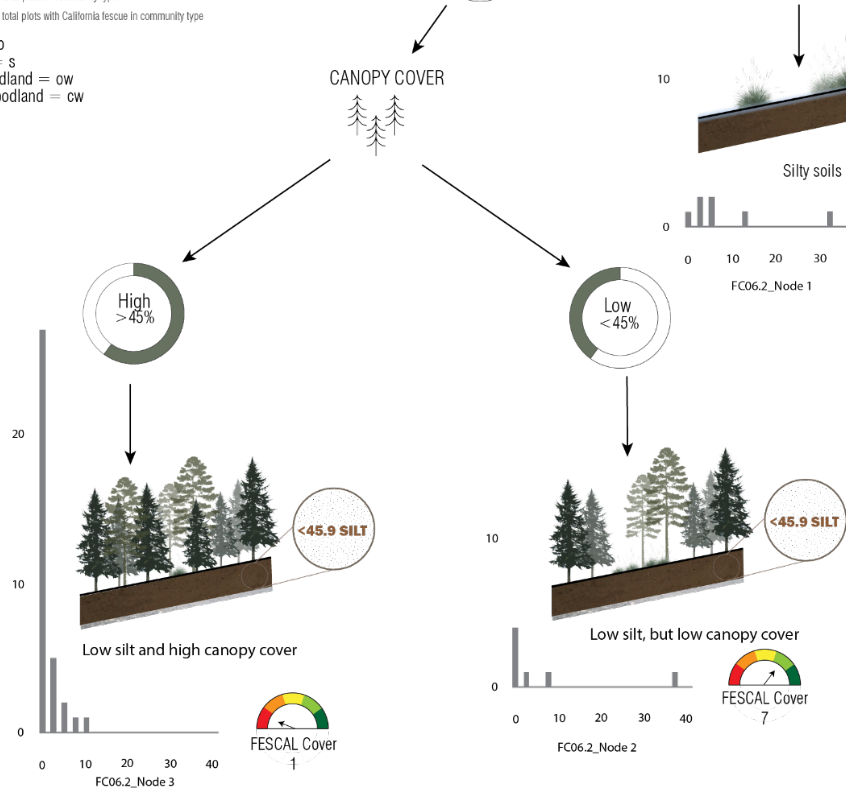


Prairie = p
Savanna = s
Open Woodland = ow
Closed Woodland = cw
Forest = f

California fescue is more tolerant of canopy cover than Roemers fescue, but it still prefers savanna, prairie, and open woodland environments to closed woodland and forests

2006 FESCAL CART 2



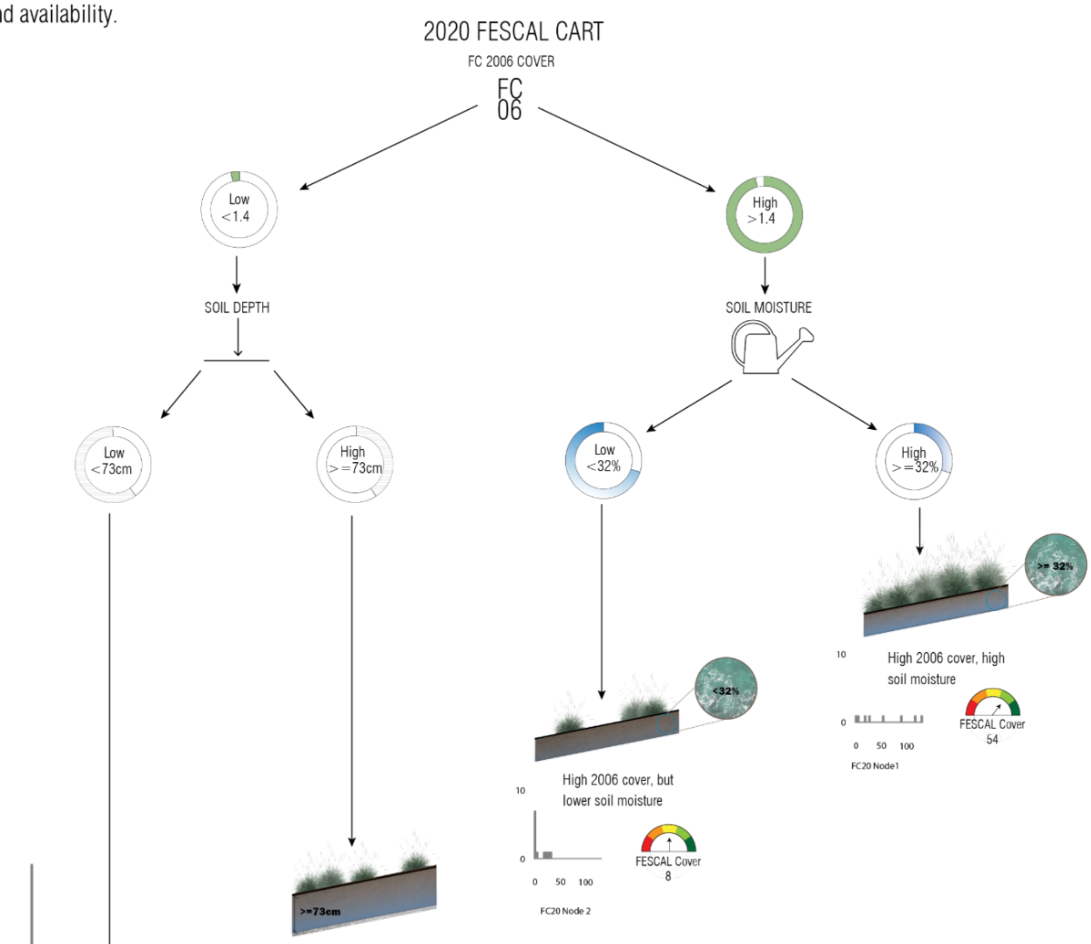


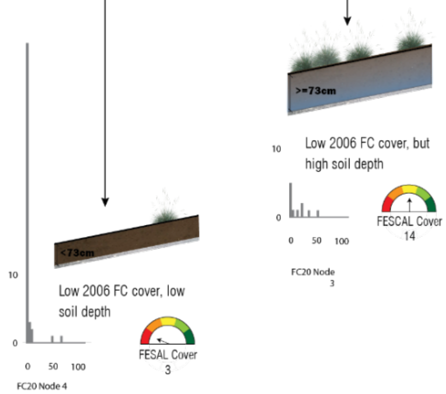
CALIFORNIA FESCUE

FESTUCA CALIFORNICA

California fescue expanded out from where it had been prior to the restoration. If there had been quite a bit of it in a plot, it did especially well where there was higher soil moisture on average year-round, since lower soil moisture limited how well the species could thrive.

Where there was little to no California fescue present prior to the restoration, soil depth defined whether California fescue could become established and thrive. Like prior to the restoration, this is also likely an issue of deep soil moisture retention and availability.





A small 2006 California Fescue community becomes a hot spot for expansion after restoration

CALIFORNIA FESCUE
FESTUCA CALIFORNICA

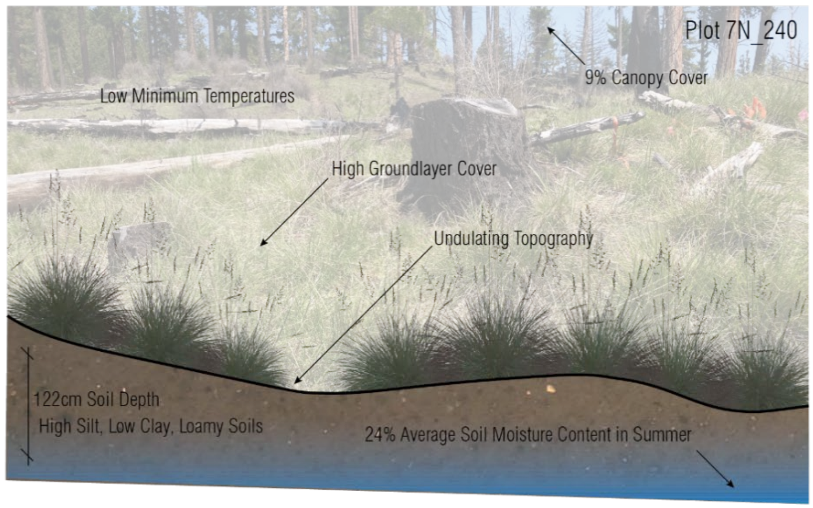
POST RESTORATION SUCCESS

Soil depth and soil moisture can be hard to detect when observing in the field. On our site, I compared the plot that saw the highest overall numbers of California fescue and the plot that saw the biggest increase after restoration both in the field and through data to find the visible and invisible characteristics that made the difference for California fescue.

Highest California fescue Numbers on Site

Why was it doing so well here?
Visible
- High ground layer cover, suggesting a productive site
- Lower canopy cover

Invisible
- Deep soils
- High soil moisture content
- Loamy, silty soils
- Low minimum temperatures

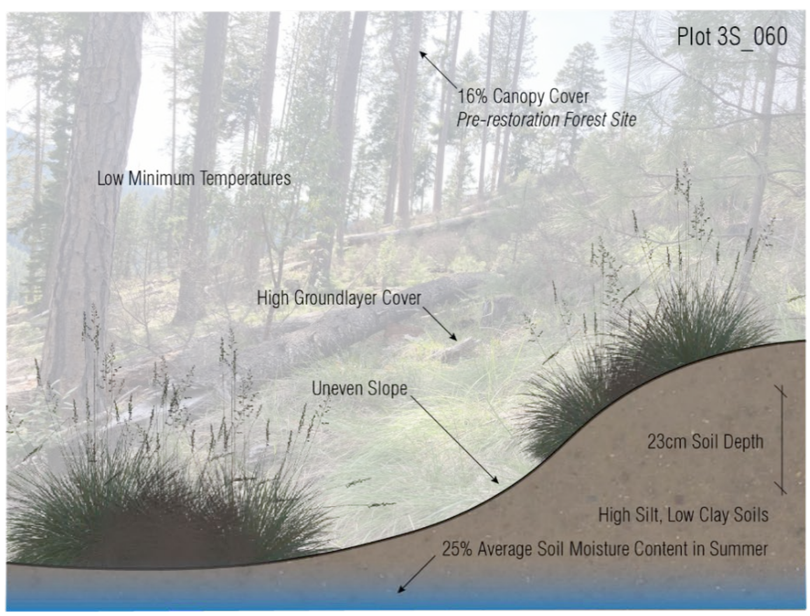


Greatest Increase After Restoration

Why did it increase so much here?

Visible
- Previously a forest site, now a savanna
- Uneven slope, allowing for moisture collection
- High ground layer cover, suggesting a productive site

Invisible
- Though shallow soil depth, high soil moisture content during drought season
- Loamy, silty soils
- Low minimum temperatures

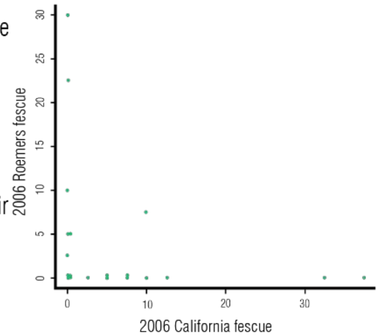


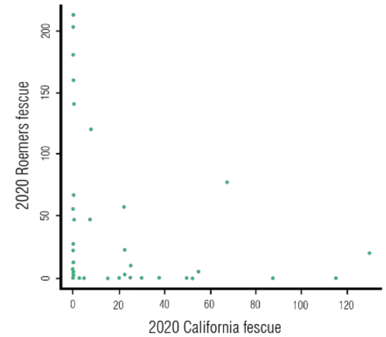
RECOMMENDED SEEDING STRATEGY

WHY NOT SEED TOGETHER?

In both pre- and post-restoration data, California fescue and Roemers fescue are rarely found together. These two scatter plots show this inverse relationship.

As the previous pages have shown, the two species require distinctly different environmental characteristics due to their life histories.



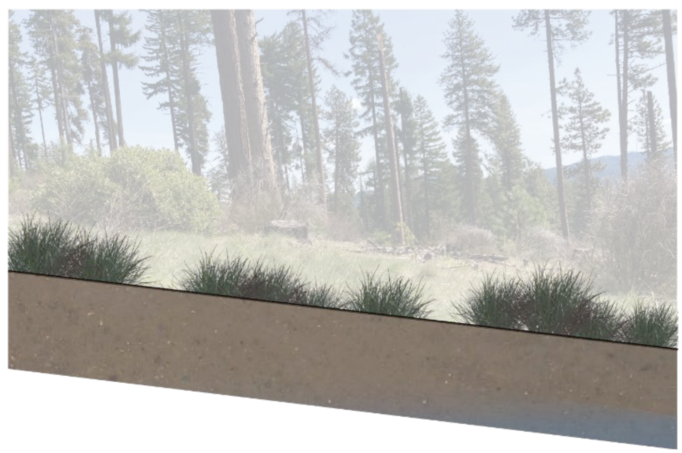


KEY DIFFERENCES

Roemer's fescue

Visible
- Prairie or Savanna
- Low ground layer cover, indicating an unproductive site

Invisible
- Shallow soils
- Low soil moisture
- Low percent silt



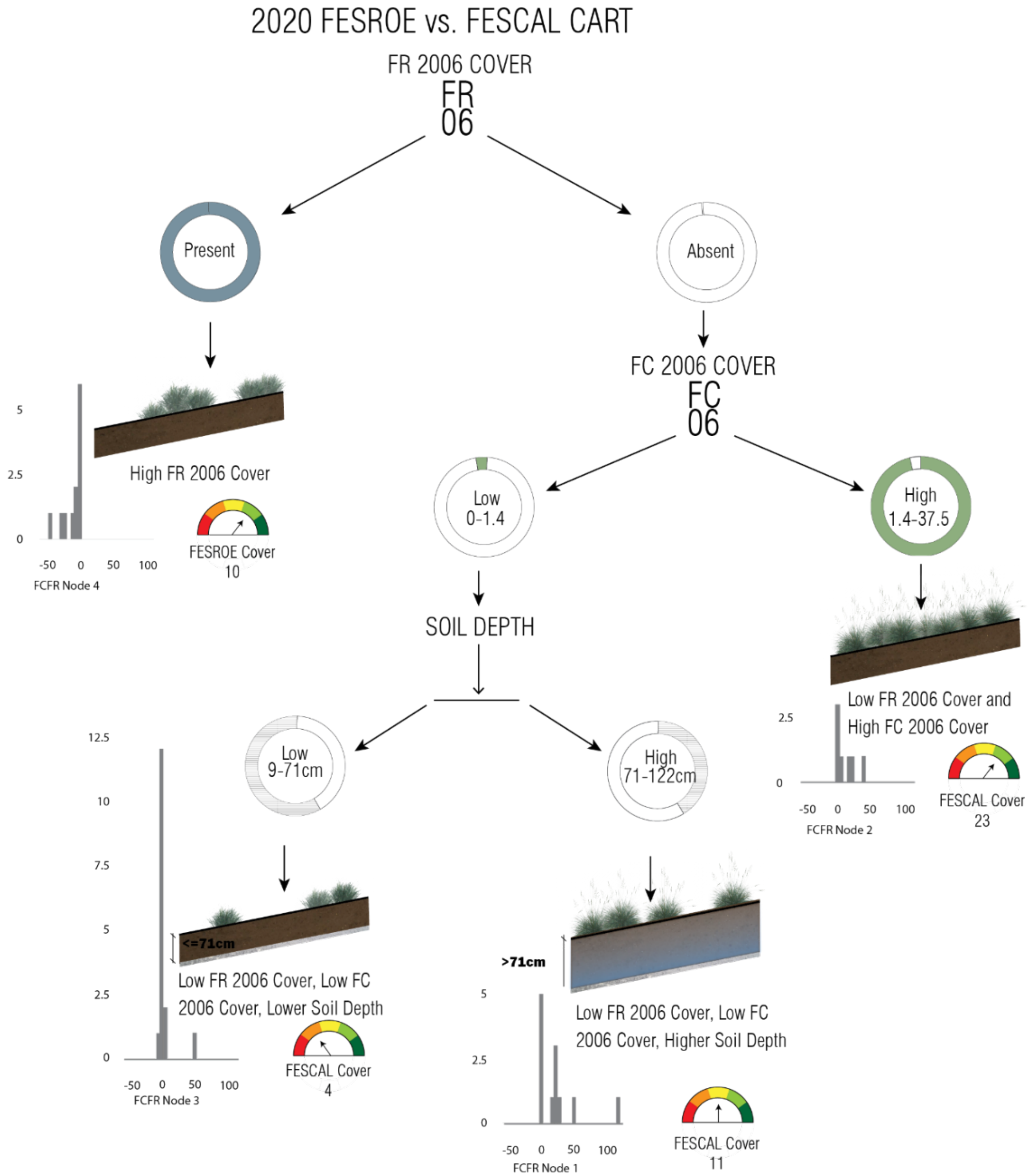
California fescue

Visible
- Prairie, Savanna, or Open Woodland
- Undulating Topography
- High ground layer cover, indicating a productive site

Invisible
- Deep soils
- Higher soil moisture
- High percent silt

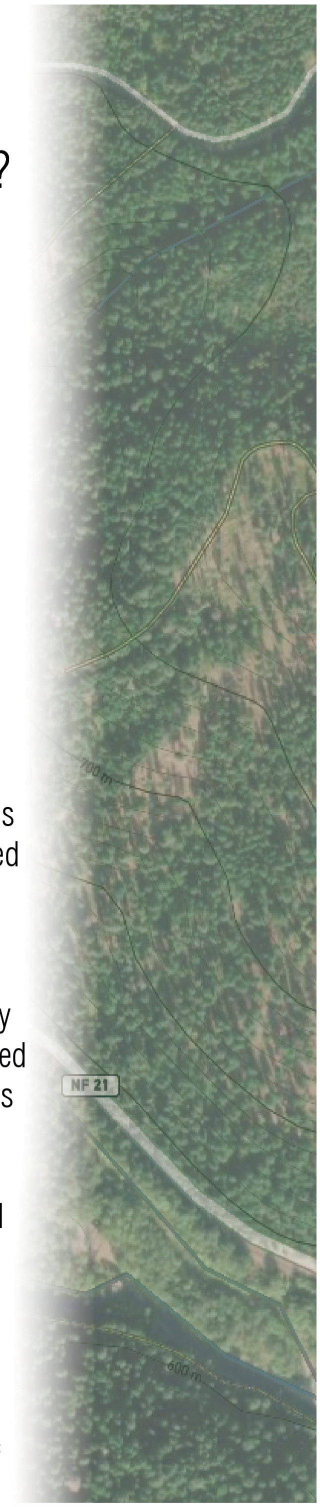
WHERE TO SEED EACH TARGET SPECIES

Overall, when deciding where to seed, looking at where each species is currently present is an effective way to decide where one or the other should be seeded. If Roemers fescue is present, it should be seeded, if California fescue is present, it should be seeded. On our site, there were some instances where California fescue was present prior to restoration, but it couldn't spread as effectively due to shallow soils. In these situations, it is worth considering whether Roemers fescue should be seeded instead, assuming canopy cover requirements are met.



RECOMMENDATIONS

WHERE SHOULD WE SEED EACH SPECIES?



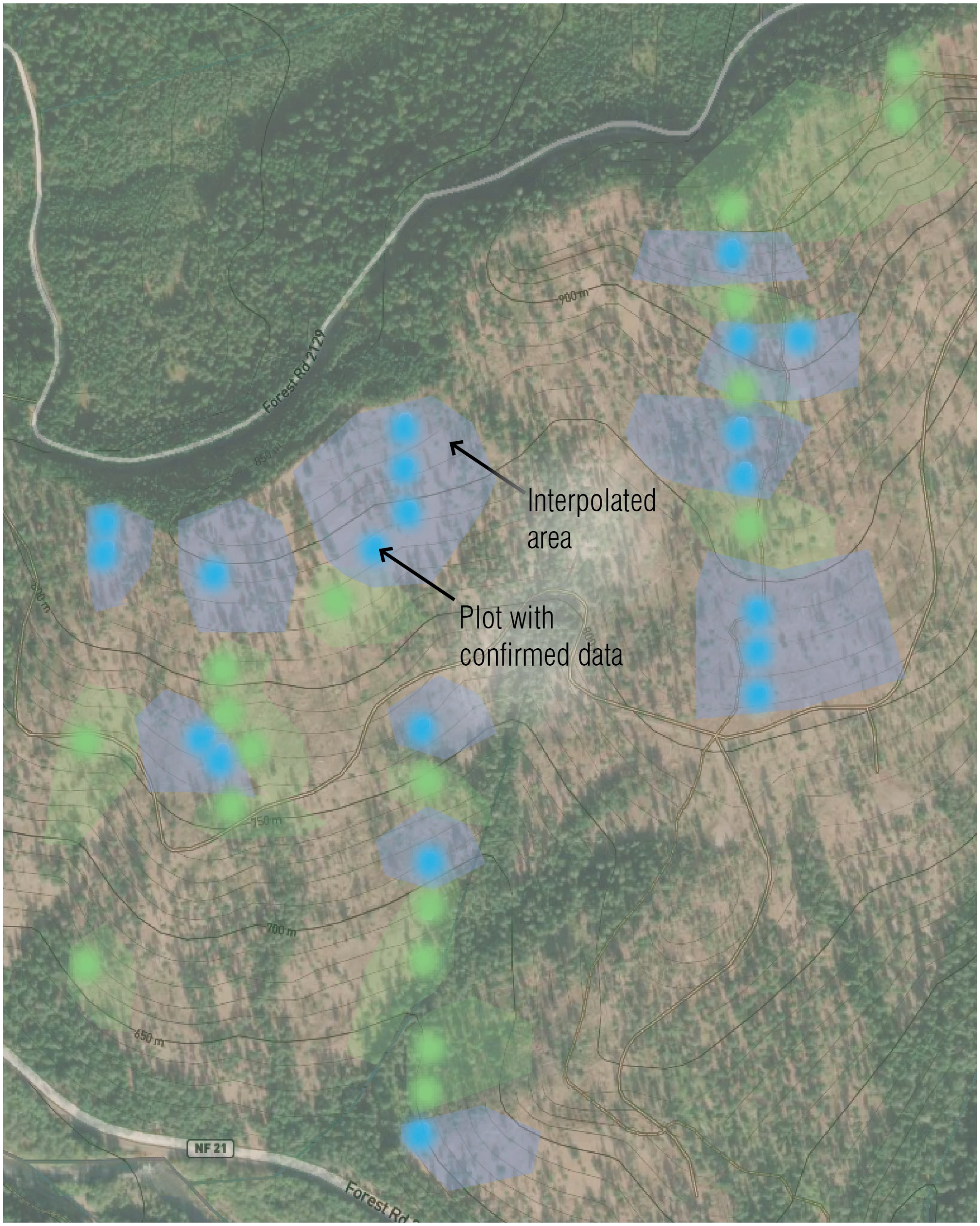
Roemers fescue:

- Below Average Soil Moisture
- Below Average Soil Depth
- Prairie Or Savanna
- Even Slope

California fescue:

- Above Average Soil Moisture
- Above Average Soil Depth
- Prairie, Savanna Or Open Woodland
- Uneven Slope

I took all of that information pulled from statistics and site observations and used it to identify places appropriate for each species to be seeded in the future. I referenced the CART results, which indicated that using averages as a threshold would be appropriate in distinguishing areas for each species. Plots where we have confirmed data inidicating which species is appropreiate are denoted by a saturated dot. From my experience with the site, and by looking at the topography, I interpolated beyond those dots to other areas that may be appropriate. For Roemers fescue, I'm suggesting the plots with below average soil moisture, and depth in prairie or savannas with evenly sloping topography. For California fescue, I'm recommending the sites with above average soil moisture and soil depth in prairies, savannas, or open woodlands in areas with uneven topography, such as drainage ways and toe slopes. Further research into intermediate zones where either species may be appropriate is needed. To fully implement this ecotope-based management approach, mapping of the full site will be necessary, requiring more continuous site data or more sophisticated methods of interpolation.


Interpolated area
Plot with confirmed data
Forest Rd 2129
900 m
750 m
700 m
650 m
NF 21

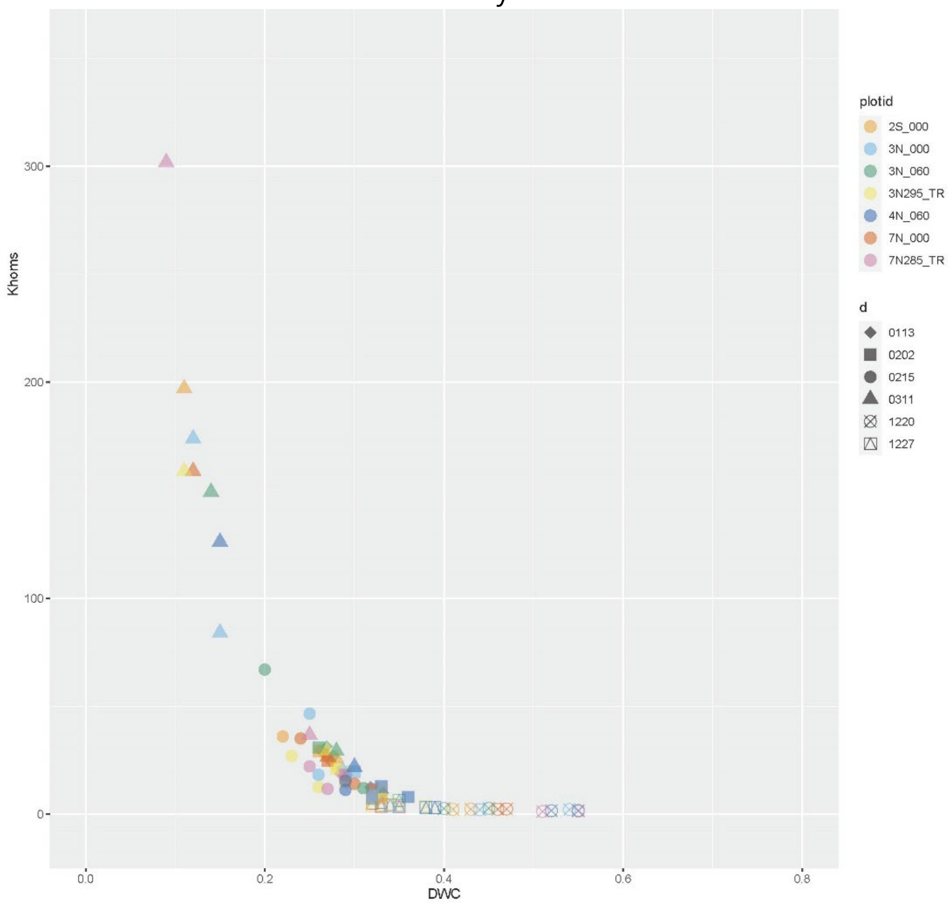
APPENDIX A

Supplemental Soil Moisture Methods

Different wood types (popular, pine, balsa) were pretested in both water and wet soil to assess water-absorption consistency among individual probes. Poplar was selected for the dual properties of the least variability in absorption (grams water / grams dry wood) and greatest strength and durability. Dowels were purchased in a single lot from a professional hobby mill for consistency. A diameter of 1/4" (6.4 mm) was selected to match the one-hour fuel sticks used to assess the moisture of woody fuels that equilibrate with atmospheric humidity in one hour. Individual probes were cut to 23 cm lengths to allow insertion 20 cm into the soil while the top 3 cm was painted red for relocation and to prevent evaporation through the top.

Dowel moisture content was calibrated to soil water tension and soil water content in the lab using Watermark Soil Moisture Sensors (Model 200S, Irrometer.com). To this end, we collected soil samples from 7 Jim's Creek plots that were representative of the soil texture range on site. Each sample was divided into two equal subsamples. Samples were sieved to remove rocks and debris with as little disruption to soil aggregate structure as possible. Soils were then packed into 2-gallon Ziploc bags that were taped to form 23 cm tall cylinders to fully accommodate length of 5 wooden probes, with a watermark sensor in the center, ½ way up from the bottom. Bags were packed with soil and stabilized inside 2-gallon airtight plastic tubs. Five 20-cm dowels were inserted into the soil ½ way between the center (sensor) and the edge. Soils were packed according to EPA standards for sensor calibration to ensure consistency among samples and to provide a firm seal around the sensors.

We connected each of the 14 probes to a Campbell Data logger and set up an automated system of data recording. We monitored sensors until all had achieved equilibrium as assessed by no more than a 1% change in soil water tension over 5 days. After the sensor had calibrated, we took tensiometer readings and measured the wet and dry dowel weight in the same way we had in the field. To record the range of moisture values we found in the field, we dried soil samples and reassembled the soil, dowels, and sensors and repeated this process. We collected measurements 5 times. Figure A.1 illustrates the relationship between the relative water content obtained from the dowels and the kiloohms recorded by the tensiometer.



Supplemental Figure A.1: Dowel Water Content (DWC) graphed against Kiloohms. Color indicated the plot location the soil was sourced from, and the shape indicates the date of collection.

APPENDIX S

Supplemental Figures and Tables

Table S1.1

Full Temperature Variable List

	Season	Time Period (all 2021)	Variables	Unit
Temperature	Growing Season	May 10th -September 23rd	avg, min, max	by plot
	Spring Season	May 10th - June 20th	avg, min, max	by plot
	Summer Season	June 20th - August 11th	avg, min, max	by plot
	Shoulder Season	May 10th - June 20th, August 11th - September 23rd	avg, min, max	by plot
	Growing Season 8am-8pm 12 hr temps	May 10th -September 23rd	avg, min, max	by plot
	Spring Season 8am-8pm 12 hr temps	May 10th - June 20th	avg, min, max	by plot
	Hot Season 8am-8pm 12 hr temps	June 20th - August 11th	avg, min, max	by plot
	Shoulder Season 8am-8pm 12 hr temps	May 10th - June 20th, August 11th - September 23rd	avg, min, max	by plot
	Season	**Collection Dates**	**Variables**	**Unit**
Moisture	Growing Season	05/09, 05/29, 07/02, 08/29, 10/03	avg, min, max	by plot
	Spring Season	05/09, 05/29	avg, min, max	by plot
	Hot Season	07/02, 08/29	avg, min, max	by plot
	Shoulder Season	05/09, 05/29, 10/03	avg, min, max	by plot

Table S1.3

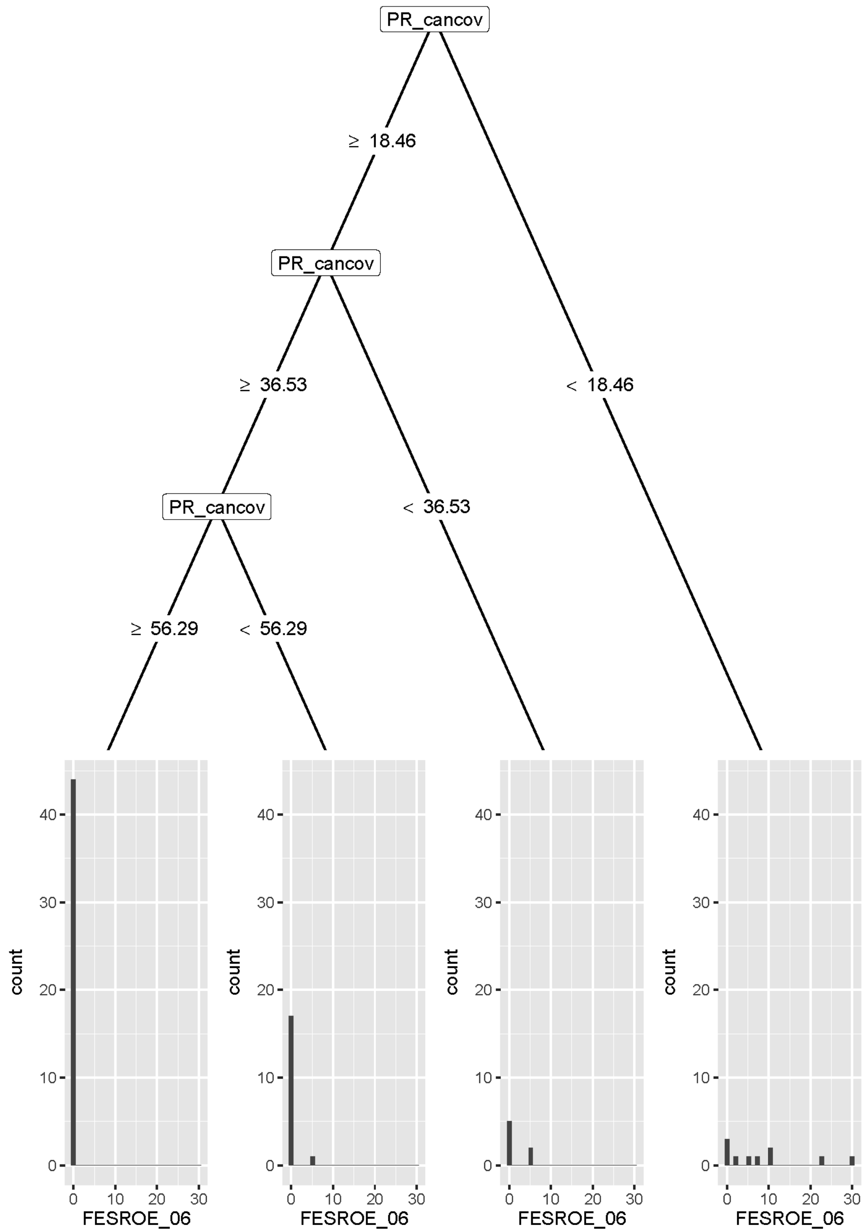
Target Species Biomass (BM) and Fitness (F) Models

		Model Variables	Estimate	Std Error	Residual Std Error	Multiple R^2	Adj R^2	F-stat	P-values	df
F. roemeri	BM		1.36E+00	2.90E-01	8.80E-01	0.84	0.82	40.87	8.48E-07	2 and 15
		Volume	6.15E-04	7.16E-05					3.51E-07	
		Volume^2	-1.60E-08	2.26E-09					3.67E-06	
	F	NA								
F. californica	BM		4.32E-01	1.61E-01	5.00E-01	0.5	0.46	13.47	8.76E-05	2 and 27
		Basal Area	4.70E-03	9.71E-04					4.74E-05	
		Basal Area ^2	-3.54E-06	8.70E-07					0.00037	
	F		- 8.63E+00	3.65E+00	9.50E-01	0.42	0.37	8.65	0.02658	2 and 24
		longest leaf	1.05E+01	2.83E+00					0.00109	
		# flowering stalks	0.03391	0.02278					0.14963	
S. arundinaceus	BM		0.076127	0.182892	0.24	0.74	0.69	15.49	0.68524	2 and 11
		longest leaf	0.008003	0.003715					0.05423	
		# flowering stalks	0.058417	0.014536					0.00202	
	F	NA								

Table S1.3
Full Variable List

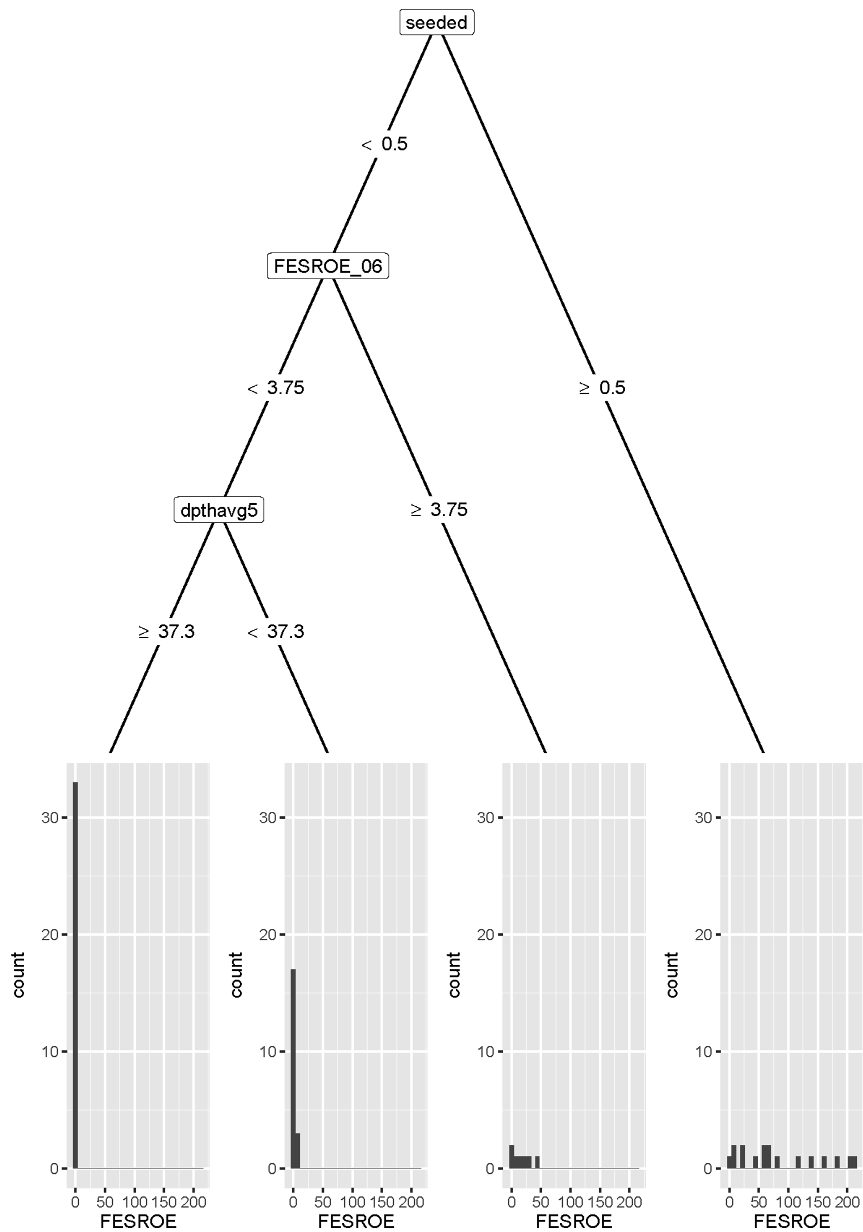
Environmental	**Biotic**
Air Temperature	Total Ground Layer Cover
Soil Moisture	Target Species Cover
Slope	Target Species Biomass
Slope Position	Target Species Fitness
Elevation	Target Species Density
Surface Rock Cover	Canopy Cover
Exposed Rock Cover	Introduced Annual Grass Cover
Moisture Index (MMI)	
Swale (y/n)	
Percent clay	
Percent silt	
Carbon Content	
Nitrogen Content	
Soil Depth (average of 5 measurements)	
Heat load/ SOA	
Treatment (Seeding/Burning)	

Supplemental Figure S1.1
Festuca roemeri Pre-restoration CART



Supplemental Figure S1.2

Festuca roemeri Post-restoration CART



Supplemental Figure S1.3

Festuca californica Pre-restoration CART1

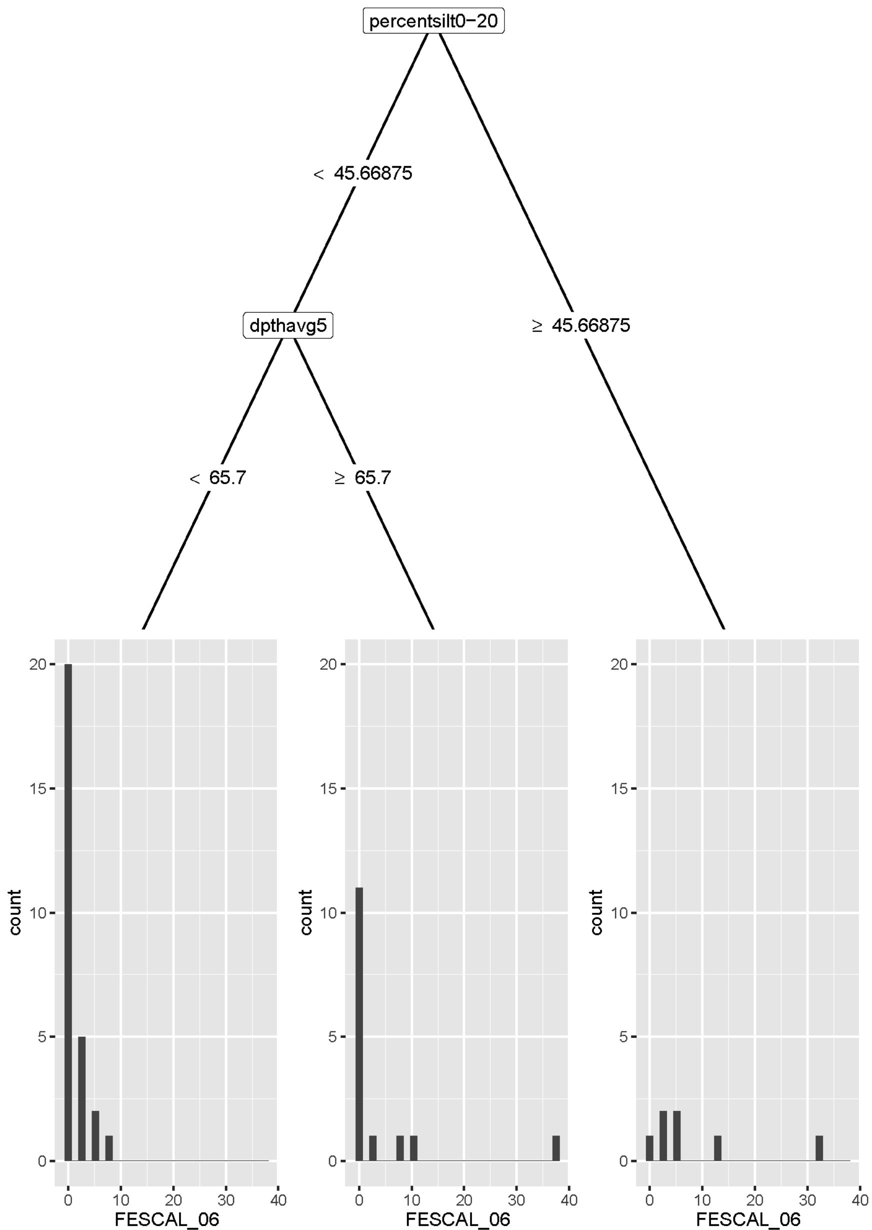


Table S1.4

Full Akaike Table with and without Outlier. Green shading indicates AICc within 2 of best model; Light green shading indicates AICc within 5 of best model; Yellow shading indicates AIC within 7 of best model

Rank	Model	Model Variables	AICc	R^2	P-value
Without					
1	A	MeanM_Spr + Mean_MinT-_12hd_Grw	152.7	0.77	0.0001
2	B	MeanM_Spr	157.2	0.61	0.0005
3	D	MeanM_Sum	157.4	0.61	0.0005
4	C	MeanM_Sum + MeanT_Spr	157.7	0.69	0.0008
With					
1	B	MeanM_Spr	178.6	0.52	0.001
2	A	MeanM_Spr + Mean_MinT-_12hd_Grw	178.7	0.62	0.007
3	C	MeanM_Sum + MeanT_Spr	180.4	0.58	0.003
4	D	MeanM_Sum	180.4	0.46	0.003

Supplemental Table S1.5

Seeded Plot Success Candidate Model Equations

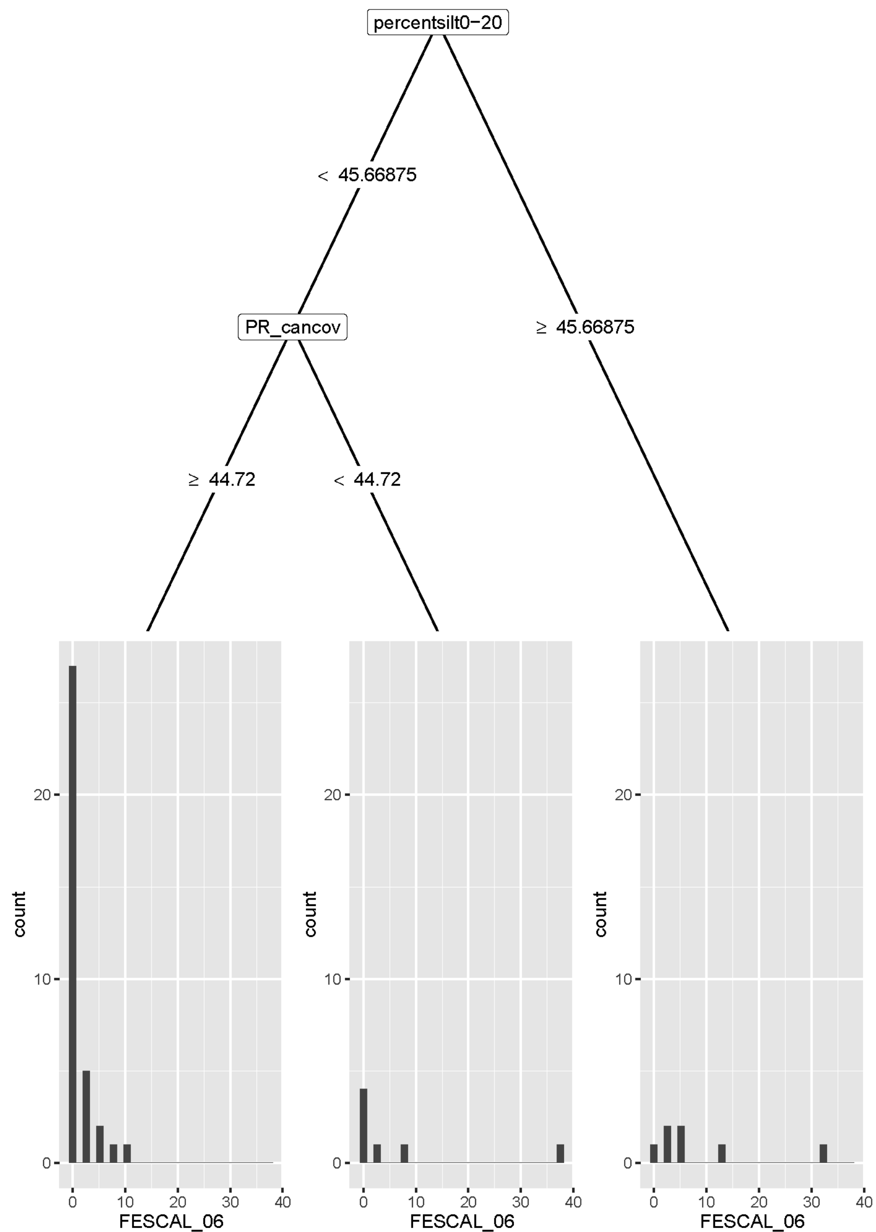
A	MeanM_Spr + Mean_MinT_12hd_Grw	Yi = -252.056 + -722.165(MeanM_Spr) + -5.438 (MinT_12hd_Avg)
B	MeanM_Spr	Yi = -298.40 + 715.37 (MeanM_Spr)
C	MeanM_Sum	Yi = 306.01 + -1343.61(MeanM_Sum)
D	MeanM_Sum + MeanT_Spr	Yi = 1120.86 + -1460.52(MeanM_Sum) + -57.19(MeanT_Spr)

With Outlier

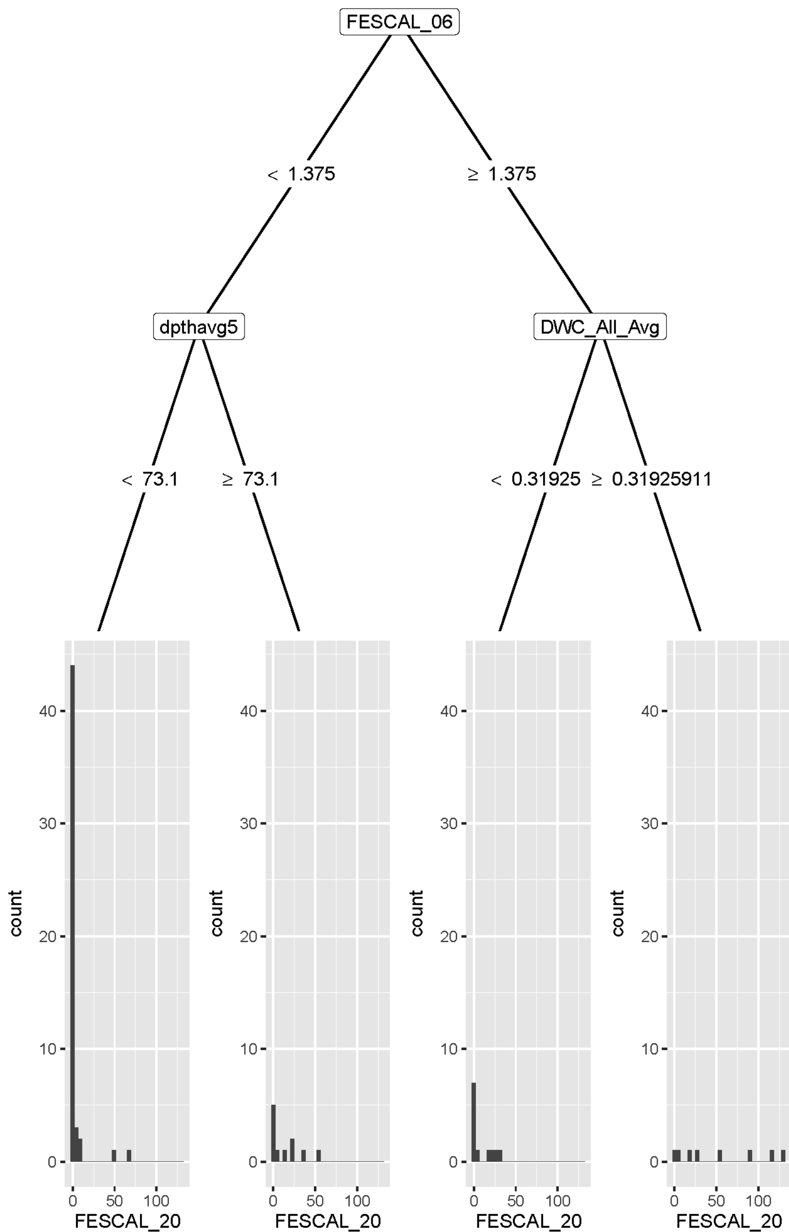
A	MeanM_Spr +Mean_MinT_12hd_Grw	Yi = -222.35 + -716.81(MeanM_Spr) + -37.35 (MinT_12hd_Avg)
B	MeanM_Spr	Yi = -255.24 + -594.62 (MeanM_Spr)
C	MeanM_Sum	Yi = 255.88 + -1160.99(MeanM_Sum)
D	MeanM_Sum + MeanT_Spr	Yi = 780.79 + -1253.47(MeanM_Sum) + -36.5(MeanT_Spr)

Without Outlier

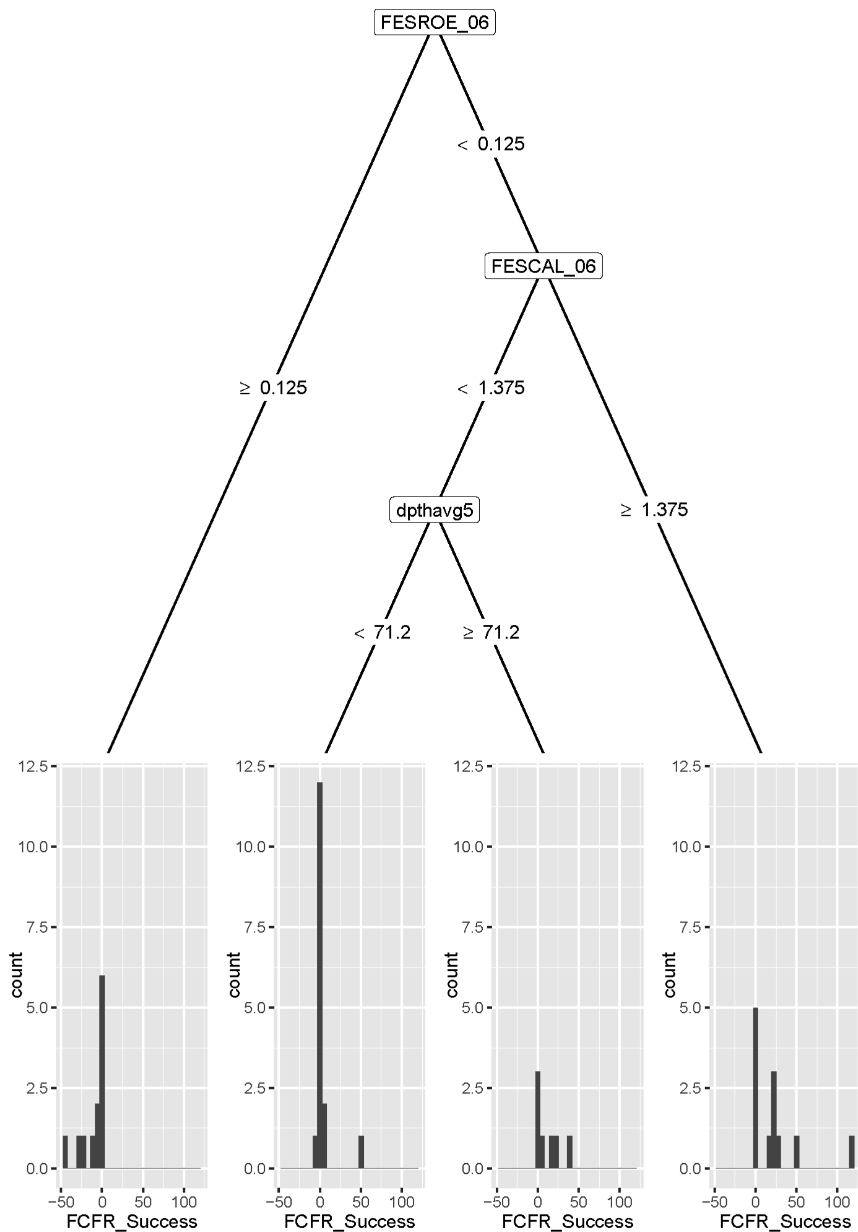
Supplemental Figure S1.4
Festuca californica Pre-restoration CART2



Supplemental Figure S1.5
Festuca californica Post-restoration CART



Supplemental Figure S1.6
Festuca californica vs. Festuca roemeri



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