ASSESSING RELOCATION HABITATS AND ASSISTED MIGRATION OF THE LASSICS LUPINE, AN ENDANGERED CALIFORNIA SERPENTINE-ENDEMIC

By

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ABSTRACT

ASSESSING RELOCATION HABITATS AND ASSISTED MIGRATION OF THE LASSICS LUPINE, AN ENDANGERED CALIFORNIA SERPENTINE-ENDEMIC

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The Lassics lupine, *Lupinus constancei*, is a serpentine species endemic to the Lassics Mountains of northern California, listed as critically imperiled and federally endangered. Increased encroachment from reduced fire intervals has led to elevated herbivory from small mammals. While deployment of exclosure cages has decreased negative impacts, diminishing snowpack from shifting climate continues to threaten the Lassics lupine. To locate possible refugia, I evaluated alternative sites for assisted migration. I built a habitat suitability model (HSM) using MaxEnt software and WorldClim variables to predict optimal habitat. I then evaluated aerial imagery, topography, and geology to identify areas for microhabitat data collection. The final study sites included Black Rock, Bug Creek Butte, Dry Lake, and Red Mountain, and were compared to the Lassics lupine demographic monitoring transects. Although soil temperature data suggested the four sites were not statistically different from the monitoring transects, more data should be evaluated prior to translocation to ensure microhabitat features are compatible for the Lassics lupine. Soil elemental analyses showed a high similarity between the Lassics lupine habitat, Black Rock, and Red Mountain; similar botanical diversity existed within Red Mountain and the Lassics lupine demographic monitoring transects. According to the HSM, the most important variable for modeling optimal habitat was precipitation of the wettest quarter of the year. This research informs agencies of suitable habitat for assisted migration of the Lassics lupine and provides insight into building HSMs with small datasets to inform research for other imperiled species.

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INTRODUCTION

The California Floristic Province (CFP) is one of 36 recognized biodiversity hotspots in the world (Cincotta et al. 2000; Conservation International 2021; Loarie 2008). There are two qualifiers for a region to be categorized as a biodiversity hotspot: at least 1,500 endemic vascular plant species must be present, and 30% or less of the native habitat has been lost due to anthropogenic impacts (Cincotta et al. 2000; Conservation International 2021). The CFP includes significant areas with ultramafic geology in western North America (Kruckeberg 1992). Of California's statewide endemic plant species, 12.5% are restricted to soils that are derived from ultramafic bedrock (Alexander 2011; Safford et al. 2005). Generally derived from the earth's mantle, ultramafic rocks have high levels of magnesium and iron and low levels of silica (Kierczak et al. 2021). Soils formed from ultramafic rocks are referred to as "serpentine soils" and are characterized by high concentrations of heavy metals, a low calcium to magnesium ratio, limited macronutrients, and low water-holding capacity (Alexander 2011; Brady et al. 2005). In northwestern California, most ultramafic rocks are composed of peridotite or its metamorphic derivative serpentinite, with resulting soils that are nutrient-imbalanced, toxic, and are either devoid of vegetation or have a stunted, edaphic stress-tolerant flora (Alexander 2011; Kruckeberg 1992).

While just 1.5% of California's land area features ultramafic geology, more than a tenth of the state's endemic plant species inhabit serpentine soils; these serpentine endemic species are taxonomically diverse with 246 species occurring in 103 genera and

41 families (Safford et al. 2005). This high proportion of endemic species restricted to serpentine soils highlights their importance in the CFP. My study focused on the North Coast Ranges and Klamath Ranges, which together host more than half of the serpentine-endemic plant species in the state (Safford et al. 2005).

The Lassics lupine, *Lupinus constancei* T.W. Nelson & J.P. Nelson (Fabaceae subfam. Faboideae), is an endangered serpentine-endemic species found only in the Lassics Mountain Range of Humboldt and Trinity counties in northwestern California (Calflora 2024; Nelson and Nelson 1983). Growing up to 15 cm in height, the Lassics lupine has a basal rosette of palmately compound leaves, a dense silvery tomentum on its fruits, calyxes, and foliage, and clustered inflorescences between 3 - 5 cm tall with bicolored pink and white flowers (Baldwin et al. 2012). The Lassics lupine was described in 1983 based on the type collection made in 1972 by T.W. Nelson & J.P. Nelson (Calflora 2024; Nelson and Nelson 1983). The lack of documentation of the species prior to its formal description has made determination of its historical geographic distribution problematic. In particular, it is unknown whether the species may have occurred outside of its current distribution area in the Lassics Mountains (Calflora 2024; California Department of Fish and Wildlife 2020; Imper 2016).

The Lassics lupine may be the rarest and most endangered plant species in northwestern California (Imper 2016). It has a California Rare Plant Rank of 1B.1, meaning it is rare, threatened and endangered in California, with more than 80% of its extant population under threat (California Native Plant Society 2020). NatureServe (2021) has designated the Lassics lupine with a State Rank of S1 and a Global Rank of

G1, indicating that it is critically imperiled and has a high risk of extinction. Additionally, it is Federally and State listed as Endangered under the Endangered Species Act by the USFWS (Endangered and Threatened 2023).

Encroachment, herbivory, and rapidly changing environmental conditions all limit the ability of the Lassics lupine to maintain or widen its current range (Imper 2016). Restricted to just one place in the world, the Lassics Mountains, this species is at risk of extinction due to several factors. With reduced fire intervals in the Lassics Wilderness, an increase in vegetation has simultaneously diminished habitats that could function as local refugia and has enhanced protection of small mammals from predation (Carothers 2008; Cate 2016; Kurkjian et al. 2017; Imper 2016). Small mammals have had severe impacts on the Lassics lupine from proliferated grazing pressure (Carothers 2008; Cate 2016; Kurkjian et al. 2017). For over two decades, interagency efforts to deploy exclosure cages have helped to ameliorate the effects of herbivory (Kurkjian et al. 2017; Imper 2016). Without the intensive management of this species, however, the Lassics lupine is projected to face extinction due to exhaustive browsing by rodents over the next fifty years (Kurkjian et al. 2017). Even with caging efforts continuing to be implemented on an annual basis, research suggests that under extreme climate change scenarios there remains a 51% chance of the Lassics lupine going extinct over the same time period (Reibsome 2022). The impacts of climate change will continue to push montane plant species like the Lassics lupine to their upper elevational edge of their ranges, putting pressure on management to explore potential alternative habitats to provide refuge from a changing climate (Chen et al. 2011; Dirnböck et al. 2011; Elsen and Tingley 2015; Imper 2016; Lamprecht et al. 2018; Nomoto & Alexander 2021; Reibsome 2022).

Planned relocation of sensitive species (hereafter referred to as "assisted migration") is a vital component of conservation (Loarie 2008; Vitt et al. 2009). Assisted migration involves human-facilitated movement of species in response to climate change or other environmental threats, resulting in expansion into habitats that could not be reached via natural dispersal (Vitt et al. 2010). Constraints imposed by extreme edaphic conditions, other biotic and abiotic factors, and poor long-distance seed dispersal make the Lassics lupine a promising candidate for assisted migration (Imper 2016; Nelson and Nelson 1983). Since small populations of rare, spatially isolated plants often have low genetic diversity and therefore reduced adaptability to changing environments, their assisted migration requires careful assessment of microhabitat characteristics of potential habitats (Harrison et al. 2008; Harrison et al. 2011).

While assisted migration has the potential to provide vulnerable species like the Lassics lupine with relief from extinction, translocation of species into new habitats can pose risks. Assisted migration can lead to unwanted effects on the species in question, such as genetic bottlenecking and hybridization with closely related taxa (Hufford & Mazer 2003). Translocated species may also become invasive in the newly inhabited locale (Simberloff 2005). Similarly, the relocation of species can function as a vector for the introduction of non-native invasive species during test trials or site evaluation (Argüelles-Moyao & Galicia 2023). Valuable resources may also be diverted from restoration activities on the focal species current habitat, or preservation of larger communities at risk (Fazey & Fischer 2009). Assisted migration has numerous positive and negative aspects, but that does not negate the importance of exploring alternative habitats to help conserve species in peril. A myriad of aspects must be considered prior to field experiments involving relocation of a species, which can aid in alleviating the negative components commonly associated with assisted migration.

Habitat suitability modeling (HSM) is a commonly applied habitat niche modeling technique for identifying suitable environments for rare and at-risk species (Deb et al. 2023; Federov et al. 2021; Hällfors et al. 2016; Lannuzel et al. 2021; Ye et al. 2021). The preferred approach for producing HSMs uses environmental and species occurrence-only data analyzed with MaxEnt software (Merow et al. 2013; Phillips & Dudík 2008). Additionally, MaxEnt can produce high quality habitat models even with small sample sizes of occurrence data (Bean et al. 2012; Elith et al. 2011; Phillips & Dudík 2008; Shcheglovitova & Anderson 2013). Thus, MaxEnt is an ideal HSM analytic program for the Lassics lupine given the limited occurrence data for the species.

Here I describe a three-tiered approach for identifying potential relocation habitats for the Lassics lupine (Wu & Smeins 2000). The first assessment involved building an HSM with WorldClim environmental variables to identify climatically suitable habitats on a regional scale. The second assessment used geographical information systems (GIS) to analyze aerial imagery as well as topographical and geological data to identify sites for ground-truthing. The third assessment ground-truthed the predicted suitable sites and collected microhabitat data for further evaluation. Plant community composition and temperature, elemental, and textural characteristics of soil were analyzed for this study.

These data were then compared to the current Lassics lupine locale to determine the most suitable sites for assisted migration of the Lassics lupine.

This research provides managers including USFWS and the US Forest Service (USFS) of the US Department of Agriculture (USDA) preliminary data to support continued assessment of assisted migration. Future research for other endangered species can also be informed by the results of this study.

METHODS

Regional Assessment

Study Area

The study area for my research included two subregions within the CFP: the North Coast Ranges and the Klamath Ranges of northern California. Geologically, both subregions are serpentine-rich, with the North Coast Ranges being largely composed of the sedimentary Franciscan Complex, while the Klamath Ranges are formed by older metamorphic and plutonic rocks (Jepson Flora Project 2024). Both subregions are characterized by abundant seasonal precipitation (Jepson Flora Project 2024; Skinner et al. 2006). The North Coast Ranges have mild summer and winter temperatures and high levels of rainfall, while the Klamath Ranges have hot dry summers and cool wet winters with heavy snow cover (Jepson Flora Project 2024; Skinner et al. 2006). Within these subregions, forests are predominantly mixed-evergreen and mixed-hardwood as well as montane and subalpine conifer (Jepson Flora Project 2024; Whittaker 2006).

Variables

The HSM was built using environmental variables as predictors and the Lassics lupine occurrence data as the response variable. The environmental variables (Table 1) were obtained from WorldClim version 2 at one km^2 resolution (Fick & Hijmans 2017). Environmental variables were created using data obtained from weather stations and interpolated values (Fick & Hijmans 2017). These occurrence data were obtained from the SRNF of USFS and were collected from systematic surveys within the Lassics Mountains conducted by USFS to determine high concentrations of the Lassics lupine for annual demographic monitoring (J. McRae, pers. comm., 2020). Environmental variables and occurrence data were projected into the World Geodetic System 1984 (WGS 84) datum and Universal Transverse Mercator (UTM) Zone 10 North using ArcGIS Pro 3.0.2 (Esri 2022). When projecting, the variables were resampled using the same one km^2 resolution as well as bilinear interpolation rather than the default nearest neighbor (Esri 2022; Phillips et al. 2006). To avoid multicollinearity between the environmental variables and reduce the chances of over-fitting the model, Spearman's correlation coefficient was calculated using the corr( ) function in *stats* package of R 4.1.1 (R Core Team 2021; Dormann et al. 2013; Merow et al. 2013). Spearman's was chosen as a correlation metric over the standard Pearson's correlation coefficient because it is more applicable to the non-parametric WorldClim data (Morales-Barbero & Vega-Álvarez 2019; Dormann et al. 2013).

Variable Selection

The environmental variables used to build the HSM were selected based on expert opinion, MaxEnt percent contribution to the model, and an absolute Spearman's rho correlation value of less than 0.7 (D. Imper, pers. comm., 2021; Phillips 2010; Gogol-Prokurat 2011). Additionally, the covariates were also evaluated by the response curves produced within MaxEnt to show how each covariate impacted the model prediction when used together and as univariate models. The first model employed nine environmental variables relevant to the life history traits of the Lassics lupine and were selected by expert opinion (Table 1). Variables with a less than one percent contribution to the model and an absolute rho value greater than 0.7 were removed. Two WorldClim environmental variables were used to build the final HSM: mean temperature of the coldest quarter of the year (BIO11) and precipitation of the wettest quarter of the year (BIO16).

Habitat Suitability Model

The area of interest (AOI) used to build the HSM encompassed six northern California counties: Del Norte, Siskiyou, Shasta, Humboldt, Trinity, and Tehama. This AOI was chosen to encompass the ultramafic geology present within northern California. Oregon was not included within the AOI since a larger AOI with so few occurrence data points would have made the HSM more prone to being over-fit (Wang et al. 2021). Additionally, the geological GIS data for the state of Oregon was characterized differently from the state of California (Horton 2017). For these reasons, only northern California was included within the AOI for this study.

Suitable habitat for the Lassics lupine was statistically modeled using MaxEnt software V 3.4.4 (Phillips et al. 2020). MaxEnt can be optimized to a particular dataset by manipulating the feature classes and regularization multiplier, both of which provide different restrictions to the model depending on sample size (Morales et al. 2017; Phillips & Dudík 2008; Radosavljevic & Anderson 2014). The feature class combinations assessed for this research included linear, quadratic, and "auto-features," because they are optimal for small sample sizes (N<10) (Anderson & Gonzalez 2011). The larger the regularization multiplier the more the model is penalized for its use of parameters, thereby reducing over fitting (Merow et al. 2013; Anderson & Gonzalez 2011; Radosavljevic & Anderson 2014). The regularization multipliers evaluated for this research included one, two, five, 10, 15, and 20 (Morales et al. 2017). Using the aforementioned feature classes and regularization multiplier combinations, a total of 18 models were assessed. Each model run was characterized by 100 replicates and a maximum iteration of 5000 to allow for convergence of the model (Young et al. 2011; Phillips et al. 2006).

Model Selection

MaxEnt models were evaluated using the area under the curve (AUC) of the receiver operator characteristic (ROC) curve, Akaike's Information Criterion corrected (AICc), and qualitative assessment (Anderson & Gonzalez 2011; Rawat et al. 2017). Models with AUC values of one are perfect at predicting suitable habitat, while AUC values of 0.5 are equivalent to suitability being randomly assigned (Phillips et al. 2006). Although AUC is the standard metric for MaxEnt model selection, it tends to become inflated when there are few occurrence points (Lobo et al. 2008). Therefore, using additional metrics for model selection such as AICc was imperative. AICc is a widely accepted metric for model selection because it penalizes the use of a high number of parameters (Burnham & Anderson 2004; Sen & Shitan 2002; Wisz & Guisan 2009;

Warren & Seifert 2011). AICc is preferential for this research when compared to the classic AIC as the value is corrected for small sample sizes (Burnham & Anderson 2004). Qualitative assessments of the model outputs were done to ensure appropriate suitable habitat was predicted in the final model based on species life history traits (e.g., suitable habitat would not be found along the coast at low elevations; Anderson & Gonzalez 2011). The final HSM employed linear-quadratic feature classes and a regularization multiplier of five to encourage restrictions on the model (Merow et al. 2013; Philip et al. 2006).

Model Testing

Testing the final model for uncertainty was done using the Monte Carlo MaxEnt tool within BlueSpray version B42 (SchoonerTurtles 2020). Injecting noise into covariates is a means of sensitivity testing that can aid in evaluating model performance (Graham & Kimble 2018; Van der Lee et al. 2006). For HSMs that have a large AOI, injecting noise into the environmental covariates is important because it can highlight areas that may have more nuanced environmental characteristics than the original interpolated data suggested (Graham & Kimble 2018). In other words, injecting noise into the independent variables provides a metric for determining areas that have low or high confidence as suitable habitat (Graham & Kimble 2018). The same feature classes and regularization multipliers from the final HSM were used for the models injected with noise: linear and quadratic feature classes and a regularization multiplier of five. Model quality and stability were determined by AUC and AICc. Noise was tailored to the covariate data based on the true mean and standard deviation values. The tested standard deviations were determined by using the range of values observed for each covariate. The maximum distance from the true mean as well as half of the maximum distance were used for the test standard deviations. Additionally, a standard deviation of zero was also evaluated for the environmental variables to compare to the output of the final model. A normal distribution was used for both covariates. For BIO11, a true mean of four °C x 10 was used and standard deviation values of zero, three, and six. For BIO16, a true mean of 559 mm was used and standard deviation values of zero, 229, and 459.

Variable Importance

Variable importance was determined using the Jackknife procedure within MaxEnt. Jackknifing for variable importance provides a method for evaluating the strength of the variables used to build the model (Bradie & Leung 2016; Phillips 2010). This process involves building the model initially with all variables, then temporarily removing one variable at a time and refitting the model using the remaining variables, as well as building a univariate model with each covariate (Bradie & Leung 2016; Phillips 2010). Based on the changes observed in the models performance, variable importance is determined (Bradie & Leung 2016; Phillips 2010). If removing a variable results in reduced model performance, the variable is considered more important; this process is done iteratively with each variable to determine relative importance (Bradie & Leung 2016; Phillips 2010). Overall, this provides a basis for identifying the key variables that determine habitat suitability.

Landscape Assessment

Site Selection

For the landscape level assessment of my study, I selected potentially suitable areas from my HSM using multiple criteria to determine where ground-truthing and subsequent microhabitat data collection would occur. Sites were evaluated and selected for site visitation using data derived from geology, aerial imagery, elevation, aspect, and proximity to a road. A 30 m^2 digital elevation model (DEM) was used to produce an aspect raster and elevation band raster using ArcGIS Pro 3.0.2 to aid in selecting optimal topographic locations from the HSM (Esri 2022). Habitats with elevation above ~1480 m as well as a northern, northwestern, or western aspect were preferential, however some of the final sites did not meet the aspect requirement for various reasons. Locations greater than 0.8 km (one mi) from a road were removed due to resource constraints including time, transportation, and funding. The final sites were within or adjacent to ultramafic parent bedrock material to ensure optimal edaphic conditions and or they contained records of plant species with ultramafic affinities. Finally, aerial imagery was examined to locate sites with an open canopy and minimal shrub cover and therefore reduce the chances of future plant encroachment. Four final study sites were selected and ground-truthed in June 2022. During ground-truthing, specific study site locations were selected by systematically traversing the areas and identifying microsites with minimal to no ongoing plant encroachment, optimal aspect and slope, and an open canopy and understory.

Study Sites

Within my study area, four sites were selected from the final HSM and further evaluated for this research (Figure 1). The study sites were named after local landscape features as follows: Black Rock, Bug Creek Butte, Dry Lake, and Red Mountain. Three of the study sites occurred within the North Coast Ranges subregion within Six Rivers National Forest (SRNF) in Humboldt County: Black Rock, Bug Creek Butte, and Dry Lake. The fourth site, Red Mountain, occurred within the Klamath Ranges subregion within Shasta–Trinity National Forest (STNF) in Trinity County. The study sites were compared to the Lassics lupine monitoring transects located within the North Coast Ranges subregion, described below.

The Lassics lupine habitat is in the Lassics Mountain Wilderness in SRNF, ~69 km from the Pacific Ocean at 40°20’1” N latitude, 123°33’10” W longitude (Figure 2). The elevation ranges from ~1737 - 1791 m for the monitoring transects. The thirty-year average monthly temperatures and precipitation for the monitoring transects proximal to Mount Lassic is 2.9°C and 383.3 mm in January and 18.8°C and 9.8 mm in July according to modeled data obtained from PRISM (PRISM Climate Group 2023). Thirty-year average monthly temperatures and precipitation for Red Lassic is 3.3°C and 387.2 mm in January and 19.4°C and 9.7 mm in July (PRISM Climate Group 2023). Prominent tree species included Jeffrey pine (*Pinus jeffreyi*) and incense cedar (*Calocedrus decurrens*). The monitoring transects near Mount Lassic occur on Mesozoic plutonic parent bedrock material composed of ultramafic rocks, mostly serpentine, as well as minor peridotite, gabbro, and diabase (California Department of Conservation 2015). The

Red Lassic parent bedrock is mapped as Cretaceous and Jurassic marine sedimentary and metasedimentary rocks composed of Franciscan Complex sandstone, with minor shale, chert, limestone, conglomerate, and Franciscan mélange (California Department of Conservation 2015).

The Black Rock site is the most northerly study area (Figure 3), located in SRNF, positioned ~7.6 km to the southeast of Horse Mountain. This site is ~42 km from the Pacific Ocean, at 40°48’45” N latitude, 123°41’28” W longitude. The study site has an elevational range of ~1600 - 1605 m. The 30-year average monthly temperature and precipitation of Black Rock is 3.0°C and 484.3 mm in January and 19.7°C and 20.0 mm in July (PRISM Climate Group 2023). Prominent tree species included Jeffrey pine, Douglas-fir (*Pseudotsuga menziesii*), and incense cedar. Parent bedrock material is composed of Mesozoic plutonic ultramafic rocks, mostly serpentine, with minor peridotite, gabbro, and diabase (California Department of Conservation 2015).

The Bug Creek Butte site is ~13.7 km SSW of the Black Rock site within SRNF, ~ 45 km from the Pacific Ocean at 40°41’48” N latitude, 123°44’51” W longitude (Figure 4). The elevation ranges from ~1481 - 1483 m for the study site. Thirty-year average monthly temperatures and precipitation is 3.7°C and 477.1 mm in January and 17.7°C and 18.5 mm in July for the Bug Creek Butte study site (PRISM Climate Group 2023). Prominent tree and shrub species included Douglas-fir, incense cedar, and Brewer’s oak (*Quercus garryana* var. *breweri*). Parent bedrock material is mapped as Cretaceous and Jurassic marine sedimentary and metasedimentary rocks (California Department of Conservation 2015). Predominantly composed of Franciscan Complex sandstone, there are also smaller amounts of shale, chert, limestone, and conglomerate, including Franciscan mélange (California Department of Conservation 2015).

The third site within SRNF, the Dry Lake site, is ~4 km SSW of Signal Peak in the Lassics Mountains and is ~67 km from the Pacific Ocean at 40°18’1” N latitude, 123°34’12” W longitude (Figure 5). The elevation ranges from ~1571 - 1578 m. The thirty-year average monthly temperatures and precipitation are 3.9°C and 386.6 mm in January and 19.4°C and 9.2 mm in July (PRISM Climate Group 2023). Prominent tree species included Jeffrey pine and incense cedar. Parent bedrock material is the same as Black Rock, with Mesozoic ultramafic plutonic rocks, predominantly serpentine with minor components of peridotite, gabbro, and diabase (California Department of Conservation 2015).

The fourth site, Red Mountain, is located within STNF, ~ 104 km from the Pacific Ocean at 40°18’52” N latitude, 123°8’12” W longitude (Figure 6). The elevation ranges from ~1714 - 1715 m. Thirty-year average monthly temperatures and precipitation are 2.9°C and 388.5 mm in January, and 20.1°C and 5.5 mm in July (PRISM Climate Group 2023). Prominent tree and shrub species included Jeffrey pine, Douglas-fir, and Brewer’s oak. Parent bedrock material for this site is the same as Black Rock and Dry Lake: primarily Mesozoic ultramafic plutonic rocks, most frequently serpentine, with minor peridotite, gabbro, and diabase (California Department of Conservation 2015).

Site Assessment

Data Collection

To further evaluate the four study sites selected for ground-truthing, microhabitat data was collected from each study site. Soil temperature, soil elemental and textural composition, and floristics data were collected. These data were used to evaluate each of the four study sites for compatibility with the Lassics lupine and subsequent assisted migration. Climatic data loggers were deployed in mid - October of 2022 and retrieved in late - June of 2023, with data collection taking place over the course of eight months to capture the seasonal variation from winter through summer. Each study site had two Thermochron iButton devices collecting soil temperature data at 255 - minute intervals. The Thermochron iButton devices have a temperature range of -40°C - 85°C and were enclosed within a Whirl - Pak sample bag to minimize exposure to moisture. Each iButton was placed at a depth of ~10 - 15 cm and positioned on opposing sides of its respective study site 10 m apart to capture variation within the site.

Two soil samples were collected at each study site in the same soil pit used to deploy the iButton sensors. Coarse rocks and debris were removed, and test pits were dug using a hand trowel. Soil samples were obtained from a depth of ~10 - 15 cm, placed into one-gallon plastic bags and stored in a refrigerator until submission for analysis. The two samples collected from each site were combined into a single sample due to an increase in the amount required for laboratory analysis. Each of the four samples were sifted to remove large rock fragments and other coarse debris. Elemental and textural analyses were completed at A & L Western Laboratories (Appendix A).

The Protocol for Surveying and Evaluating Impacts to Special Status Native Plant Populations and Sensitive Natural Communities were used to conduct floristic surveys at each study site (California Department of Fish and Wildlife 2018). Surveys occurred on the following dates: June 16, 2022, and June 25, 2023, at Black rock and Bug Creek Butte; June 25, 2022, and July 9, 2023, at Dry Lake; and June 22, 2022, and July 8, 2023, at Red Mountain. Floristic data used for both the Shannon-Weiner diversity indices and the Jaccard similarity index were collected in a 30 m buffer surrounding the data loggers with a survey area of 0.4 ha (one ac). Additional floristics data was collected in the environment surrounding the study sites to characterize adjacent habitat, with a survey area of 0.8 ha (two ac). All observed plant species were identified to the lowest taxonomic rank necessary to determine rarity (Appendix B). Plants were keyed using The Jepson Manual and the Jepson eflora (Baldwin et al. 2012; Jepson Flora Project 2024).

Data Analysis

Soil Temperature

Microhabitat data were analyzed to determine the similarity of each of the four study sites to the Lassics lupine habitat. This was done to quantify how suitable each site was for assisted migration trials of the Lassics lupine. Soil temperature data were analyzed by conducting a permutational multivariate analysis of variance (PERMANOVA) statistical test to determine if the seasonal soil temperature variation for each of the four study sites were statistically different from the current Lassics lupine habitat. PERMANOVA was chosen instead of analysis of variance (ANOVA) because PERMANOVA is optimal for data with multiple variables lacking a normal distribution (Anderson 2001; Anderson & Walsh 2013). The PERMANOVA was performed using the adonis2( ) function in the *vegan* package in R 4.1.1 with an unrestricted permutation with 999 iterations and a Euclidean distance method (R Core Team 2021). Soil temperatures from the four study sites were compared to soil temperatures of the Lassics lupine North and South Saddle and Red Lassic demographic monitoring transects during the same time period of October 16, 2022 to June 25, 2023; data from the North Saddle were obtained from a prior season (2020 - 2021) due to a lack of data for the 2022 - 2023 season, and insufficient data for the 2021 - 2022 field season (Appendix C). Soil temperature data collected from the demographic monitoring transects were obtained from similar depths as the data loggers deployed at the four study sites. The two demographic monitoring transects were chosen because they are the most productive habitats for the Lassics lupine. Data collected from the two iButton data loggers from each study site were adjusted to average daily values to be comparable to data collected in the Lassics using HOBO onset micro station sensors. Soil elemental characteristics from all four study sites were compared to the mean values obtained from 10 soil samples collected at similar depth, in habitat occupied by Lassics lupine within the Lassics Mountains (Appendix D; Alexander 2008; Imper 2012).

Soil Characteristics

Soil elemental data were evaluated using a principal components analysis (PCA) to determine which soil characteristics contributed the most to the variations in the data, represented by principal components (Shlens 2014). The PCA biplot was created using PAST statistic software v 4.16c (Hammer et al. 2001). A scree plot was produced to help visualize the relative importance of each principal component using the eigenvalues, which indicate the measure of variance depicted by each component (Rodionova et al. 2021). A dendrogram cluster analysis was also performed on the soil characteristics to determine which study sites were most similar to the current habitat of the Lassics lupine by identifying natural groupings within the data (Jolliffe et al. 1989). The cluster analysis was performed using the adonis2( ) function in the *vegan* package in R 4.1.1 with a Euclidean distance method (R Core Team 2021).

Floristics

Shannon-Weiner diversity indices and a Jaccard similarity index were determined for each of the four study sites and the Lassics lupine habitat to compare the diversity and similarity of the flora present. The plant species documented within the 0.4 ha (one ac) homogeneous habitat encompassing the data loggers were used for these analyses. Flora was identified within the Lassics lupine demographic monitoring transects using personal knowledge, iNaturalist, Calflora, and the Jepson eflora (Calflora 2024; Jepson Flora Project 2024; iNaturalist 2024). The Shannon-Weiner diversity indices were performed using the hclust( ) function in the *stats* package in R 4.1.1 with a Euclidean distance method (R Core Team 2021). The Jaccard similarity index was performed using the vegdist( ) function in the *vegan* package in R 4.1.1 (R Core Team 2021).

RESULTS

Regional Assessment

Variables

The results of the Spearman's correlation plot indicated that the nine covariates selected for the initial model had varying levels of correlation, as seen in Figure 7. The final two covariates used to build the HSM were not highly correlated, with a Spearman's rho correlation value of 0.4.

Variable Selection

Response curves produced by MaxEnt indicated that the two covariates selected for building the final HSM reflected various life history traits of the Lassics lupine. Predicted habitat showed an optimal range of temperatures for the mean temperature of the coldest quarter of the year (BIO11) with an initial increase in suitable habitat with increasing temperatures, and then a stabilization of predicted suitability, followed by a decline in suitable habitat as temperatures continued to increase (Figure 8). An increase in precipitation of the wettest quarter of the year (BIO16) led to an increase in predicted suitable habitat (Figure 8).

Habitat Suitability Model

The final HSM identified potential climatically and geologically suitable habitat within Humboldt, Del Norte, Siskiyou, and Trinity Counties (Figure 9). Horse Mountain and Goat Rock, as well as less geologically suitable habitat including Bug Creek Butte and Board Camp Mountain were identified within Humboldt County (Figure 9). Within Del Norte County, suitable areas included: Sanger Peak, Lookout Mountain, Polar Bear Mountain, Bear Cub, Chimney Rock, and Ship Mountain. Within Siskiyou County, additional suitable areas included: Copper Mountain, Preston Peak, El Capitan, and Boulder Peak. Within Trinity County, Red Mountain (south of Hayfork) as well as areas within the Trinity Alps were deemed as moderately suitable, including Gibson Peak and surrounding unnamed ridgelines.

Noteworthy areas that could offer climate refugia for the Lassics lupine included Boulder Peak with an elevation of 2511 m, Preston Peak with an elevation of 2229 m, and El Capitan with an elevation of 2069 m in Siskiyou County.

Model Testing

Results from the uncertainty testing showed a large decrease in model performance when high levels of noise were injected. In BIO11, Δ AICc values ranged from four to 22, with the higher values being approximately the same Δ AICc for the models built using a regularization multiplier value of 20; AUC values did not decrease significantly, with a range of 0.9845 to 0.9456 (Table 2 - 3). For BIO16, a large decrease in model performance was observed when high levels of noise were injected, with Δ AICc values ranging from four to 67, and AUC values ranging from 0.9845 to 0.6147.

Variable Importance

Of the two covariates used to build the final HSM, the most important WorldClim variable was precipitation of the wettest quarter of the year (BIO16). Results of the jackknifing for variable importance indicated that BIO16 had the highest gain metric when the other covariate was omitted, meaning this environmental variable provided the most useful information as a univariate model in predicting suitable habitat for the Lassics lupine (Figure 10). The gain metric is a measure of goodness of fit of the model to the data, with a higher value indicating an improved fit compared to the null model (Elith et al. 2011). Additionally, when BIO16 was omitted, the model showed the highest reduction in the gain metric compared to the model excluding the other covariate (Figure 10). This means that BIO16 had a greater contribution of climatic information to the model when compared to the other variable used.

Landscape Assessment

Site Selection

Each of the four study sites included within this study varied in terms of habitat suitability based on the criteria used for selection (Figure 11). While the Black Rock study site did not meet the requirement of north - northwest or west facing aspect, it had easy access, as well as an open canopy, shrub, and tree cover. The Bug Creek Butte study site exceeded the criteria of being no more than 0.8 km (one mi) from a road by 0.4 km (0.5 mi) but offered a site potentially free of future encroachment. The Dry Lake study site was adjacent to a closely related *Lupinus* species and therefore ran the risk of hybridization but was located within the Lassics locale and offered the highest elevation within the Goat Rock area. The Red Mountain study site also did not meet the requirements of north-northwest or west facing aspect, but its remote locale may reduce the chances of recreational activities impeding planting trials.

Site Assessment

Data Analysis

Soil Temperature

Temperature fluctuations were qualitatively similar throughout the data collection period for all four study sites and Saddle and Red Lassic demographic monitoring transects (Figure 12 - 16). Soil temperatures fell to nearly zero °C in late December and remained constant until early May for Red Mountain and mid-May for Black Rock, Bug Creek Butte, and Dry Lake, suggesting that snowpack duration lasted for approximately six months for the study sites (Figure 12 - 16). Soil temperatures also fell to nearly zero °C in late December and remained relatively constant until early April on Red Lassic and in early June on the Saddle (Figure 12 - 16). This suggests that snowpack duration within the demographic monitoring transects lasted for approximately four to six months (Figure 12 - 16). The rise in temperatures from zero °C appears to be a reasonable approximation of snowmelt date, based on research conducted in the Lassics (Imper 2012). This indicates that soil temperatures, and thus snowmelt date and snowpack duration of the study sites fell within the ranges of the demographic monitoring transects. The soil temperature data from the four study sites and the demographic monitoring transects had a standard deviation of the means of 1.4°C. The mean temperature during deployment was 3.5°C for Bug Creek Butte, 3.7°C for Dry Lake, 3.9°C for the Saddle, 4.7°C for Black Rock, 5.5°C for Red Mountain, and 6.8°C for Red Lassic. The results of the PERMANOVA showed that soil temperatures of the study sites and the existing Lassics habitat did not differ significantly during the period of data collection (P = 1; Table 4).

Soil Characteristics

According to the correlative PCA biplot, the most important soil characteristics for explaining the variation across study sites in order of importance were iron, manganese, calcium-magnesium ratio, lead, potassium, magnesium, zinc, and pH (Figure 19). These soil characteristics contributed significantly to the variance explained by the first principal component in the PCA biplot. The PCA scree plot indicated 82% of the variation within the data can be explained within the first two principal components (Figure 18). Based on the clustering observed within the PCA biplot, there were several soil characteristics with high degrees of correlation. The first clustering of variables included calcium-magnesium ratio, lead, calcium, and sodium within the PCA biplot (Figure 19). There was also a high degree of clustering observed with organic matter, phosphorus, and copper (Figure 19). Additional correlations were seen between manganese, pH, and iron (Figure 19). Finally, magnesium, zinc, and total percent carbon were also highly correlated (Figure 19). Overall, the correlative PCA biplot indicated that the Lassics habitat, Red Mountain, and Black Rock were the most similar based on elemental composition and differed the most in terms of soil texture and nitrate nitrogen content. Bug Creek Butte was the least similar site when compared to the Lassics habitat based on soil characteristics (Figure 19).

The dendrogram cluster analysis indicated closely related soil characteristics between Black Rock and Red Mountain, followed by Dry Lake and the Lassics habitat, with Bug Creek Butte being the most distinct site (Figure 20).

<u>Floristics</u>

Shannon-Weiner diversity indices and Jaccard similarity index showed that the Lassics lupine habitat fell between Black Rock, Bug Creek Butte, Dry Lake, and Red Mountain in terms of diversity, and was most similar to Red Mountain according to the flora documented within the 0.4 ha (one ac) study sites (Table 5). According to the Shannon-Wiener diversity indices, the lowest plant diversity occurred at Dry Lake with a value of 2.39, followed by Black Rock at 2.48, the Lassics lupine habitat at 2.63, Red Mountain at 2.83, and finally Bug Creek Butte at 2.89. Jaccard similarity index results showed a high plant community similarity between the Lassics lupine habitat and Red Mountain study site, with a similarity value of 0.48. Dry Lake and Bug Creek Butte had the same similarity index to the Lassics lupine habitat with a value of 0.39 each, and Black Rock was the most dissimilar to the Lassics with a value of 0.3.

Using floristics data from the 0.8 ha (two ac) surrounding the study sites, Red Mountain had the highest number of plant species at 49, four of them being rare in California. Bug Creek Butte had 47 plant species, with seven of them being rare in California. Plant alpha-diversity dropped notably at Black Rock with 37 species and Dry Lake with 24 species; each of these sites had one rare plant species.

Overall, the floristic surveys yielded 110 species in 42 families. Twenty-six of these species had an ultramafic affinity ranking (Appendix B); 10 species were considered rare under the California Rare Plant Rank (CRPR), with four species classified as CRPR 1, meaning they are rare, threatened, and endangered within California and elsewhere. One such rare California endemic species observed was the scabrid alpine tarplant, *Anisocarpus scabridus* (Eastw.) B.G. Baldwin, listed as a 1B.3 endemic rare plant, with the only other known Humboldt County observation occurring in the Lassics Mountains (Calflora 2024; Jepson Flora Project 2024). The most diverse family was Asteraceae (13 species), followed by Polemoniaceae (seven species), and Liliaceae and Brassicaceae (six species each) (Appendix E).

DISCUSSION

My study indicated that there are potential suitable habitats for the Lassics lupine beyond its current locale. Additionally, it contributes to the growing body of research on HSMs for at-risk species. While few studies have worked to validate HSMs for endangered species, successful field experiments employing assisted migration have been undertaken. Draper et al. (2019) produced an HSM for the critically endangered plant *Narcissus cavanillesii*, which was under threat due to the construction of the Alqueva mega-dam in Portugal. After a decade of monitoring, the species was effectively translocated into suitable limestone derived soils. Successful assisted migration of *N. cavanillesii* was determined by its stable post-migration demographics and successful intergenerational reproduction. Similarly, Tojibaev et al. (2019) built an HSM for the rare shrub *Otostegia bucharica*, which was threatened with extinction due to the construction of a railroad in Uzbekistan. In this study, validation of the model was successful, but poaching and other anthropogenic factors severely impacted the species during the decade-long monitoring of the assisted migration. Nevertheless, *O. bucharica* was successfully translocated to alternative habitats with optimal gypsum soils obtained from the HSM. As these studies have shown, HSMs can identify habitat for at-risk species and provide real-world examples of assisted migration that have worked based on careful evaluation of microhabitat characteristics essential for success. Relocation efforts also need to be informed *a priori* by assessment of potential negative anthropogenic impacts such as resource-extraction and recreation, as well as possible herbivory impacts from small mammals.

While the Lassics lupine is a prime candidate for assisted migration given the current threats and dispersal limitations, there are multiple aspects to be considered before validating the model (Carothers 2008; Cate 2016; Kurkjian et al. 2017; Imper 2016; Reibsome 2022). Negative impacts to the source population and newly proposed locale could occur from the collection and translocation of individuals and propagules. Collecting seeds is done annually for seed propagation trials and contributions to seed banks by SRNF, and restrictions on seed collecting minimize negative impacts on the overall population structure (J. McRae, pers. comm. 2024). A portion of seeds already collected on an annual basis could be dedicated to translocation efforts to help reduce any negative impacts. Relocation of vegetatively mature individuals may also reduce the viability of the source population through removal of future reproductive individuals. Additionally, assisted migration may also include a level of invasiveness by the target species (Simberloff 2005). While these factors apply to a number of species, the Lassics lupine does not appear to respond well to competition, especially if encroaching species led to an increase in grazing on the lupine. Additionally, the lupine is notoriously difficult to propagate even within its own locale based on out-planting trials in the Lassics Mountains and by horticulturalists (Imper 2016; J. McRae, pers. comm. 2021). For these reasons, it is highly unlikely that the Lassics lupine would become invasive in new habitats, although only planting trials could reveal this. Relocation success may be improved if vegetatively mature individuals are used for assisted migration. A developed rhizosphere could accompany the plant, thereby improving establishment into the new environment by microbial communities (Guerrant & Kaye 2007; Maschinski & Wright 2006; Tojibaev et al. 2019). Other consequences of assisted migration include the allocation of resources spent on exploring other suitable habitats, instead of improving the current Lassics lupine locale. However, restoration efforts are unlikely to resolve the issue of suitable climate refugia, encouraging the exploration of alternative habitats. The ethical concerns of assisted migration emphasize the need for thorough assessment of microhabitat features in both the current and proposed habitats for the Lassics lupine to mitigate potential negative consequences.

The HSM built for this study identified the most important WorldClim environmental variable for the Lassics lupine using percent contribution and jackknifing in MaxEnt. The variable that contributed the most to predicting suitable habitat was precipitation of the wettest quarter of the year (BIO16; Figure 10). These results suggest that the Lassics lupine is sensitive to both the duration and amount of snowpack received within the Lassics Mountains. Snowpack persistence into spring maintains a favorable soil moisture content into the growing season, a crucial site characteristic for the viability of the Lassics lupine (Imper 2016). As climate warming continues to impact high elevation species like the Lassics lupine, such temperature fluctuations and extremes may negatively influence the viability of this species.

The final HSM was chosen for multiple reasons. The model had the highest AUC value (0.9845) when compared to the other 17 models, indicating that the model was successful at distinguishing suitable habitat from background points; it also had a relatively low Δ AICc value of four (Table 2). Qualitatively, the final HSM chosen predicted suitable habitat largely in high elevation montane habitats, reflecting a more accurate prediction of life history traits, as opposed to the coastal habitats predicted by models using other covariates. Results of the model testing, however, indicated that high levels of noise injected into the environmental variables may lead to uncertainty, and predicted suitable habitat should be thoroughly evaluated to confirm compatibility for field validation (Table 2 - 3).

This study faced a myriad of limitations, including data collection in the field as well as in building the model. The climatic data collection at each of the four study sites was hampered by equipment failures, reducing the amount of comparative microhabitat data. Each site had two HOBO onset micro stations that collected insolation, soil moisture and temperature. Unfortunately, these micro stations failed over the winter months and were inundated with water and eventual battery acid. This breakdown left only the iButton soil temperature data to compare to the Lassics lupine habitat. Furthermore, data collection was limited to just eight months in the field. These losses in overall data reduced the capacity for robust statistical inferences to be made. Additionally, it prevented a comparison of seasonal insolation and soil moisture dynamics, factors which have been shown to be important in distinguishing suitable habitat in the Lassics Mountains (Imper 2012).

The HSM was limited by the inability to utilize parent bedrock as a covariate to build the model. Due to the highly localized Lassics lupine occurrence points and the coarse resolution of climatic variables (one km^2), it was not feasible to include geological characteristics as variables in building the model. This is because the geology vector would have had to be converted into a raster of the same one km^2 resolution, making it highly inaccurate. Furthermore, when parent bedrock was included as a variable, the model output was skewed to areas of sedimentary parent bedrock because the Red Lassic subpopulation occurs on sandstone – mudstone. Red Lassic is, however, highly influenced by surrounding ultramafic parent bedrock. For these reasons, the ultramafic parent bedrock vector layer was instead overlaid onto the climatically suitable habitats. This allowed for the identification of areas that contained the edaphic soil conditions required for the Lassics lupine.

Each of the study sites had differing levels of suitability for the Lassics lupine as well as future planting trials. Based on the soil temperature data, all four study sites showed very closely grouped snowpack durations and snowmelts when compared to the Lassics lupine habitat, suggesting that all four of the study sites could be potentially suitable for translocation trials (Figure 12 - 16). However, soil temperature data used for this study were not free from caveats. Since a complete dataset for the North Saddle was not available for the 2021 – 2022 or 2022 - 2023 season during the same time period as the other soil temperature data, the 2020 - 2021 data were used. These data were from an unusual winter season, showing variations in temperatures inconsistent with patterns from prior years (D. Imper, pers. comm. 2024; Imper 2012). Therefore, although the PERMANOVA results indicated that no study site was statistically different from the Lassics lupine locale, additional data should be collected and analyzed to determine the degree of similarity amongst the study sites and the Lassics.

The results of the PCA biplot analysis on soil elemental and textural characteristics indicated high similarities between the Lassics lupine demographic monitoring transects, Black Rock, and Red Mountain. According to the dendrogram cluster analysis, there were close similarities between Black Rock, Red Mountain, Dry Lake, and the Lassics lupine demographic monitoring transects. These similar soil characteristics between the study sites and the Lassics demographic monitoring transects indicate possible compatibility with assisted migration trials, particularly at the Black Rock and Red Mountain study sites. However, the correlative PCA biplot and the dendrogram cluster analysis are based on a single soil sample from each study site, which are not likely representative of the mosaic of soils within these environments. When evaluating the raw values of the soil characteristics, the study sites generally did not fall within the ranges of the Lassics lupine habitat. The most important variables for the Lassics lupine soils were determined to be pH and percent sand (Imper 2012). Soils ranged in pH between 6.2 - 6.8, while sand content ranged from 81 - 91% within Lassics lupine habitat (Imper 2012). The four study sites had a range of pH between 5.4 - 6.7, and sand content ranging from 47 - 75% (Appendix D). Of the four study sites, Black Rock fell within the pH range of the Lassics lupine; not a single study site met the minimum percent sand requirements. These data suggest that more soil samples are needed to fully examine the microhabitat of the potential relocation sites for suitability of the Lassics lupine.

In terms of *ex-situ* planting trials, the Black Rock study site is easily accessible due to its proximity to the road; however, the aspect was not optimal, and recreation is a concern due to a frequented campsite located upslope from the study site. It had an optimal pH of 6.7; however, the sand content was very low at 47% compared to the average value of the 10 Lassics lupine occupied soils of 81% (Appendix D & E). The Red Mountain study site was difficult to access with a washed-out road requiring an off-road vehicle but may provide limited recreational access which could improve planting trials. The Red Mountain soil sample indicated soils were slightly acidic with a pH of 5.8 and had a low sand content at 65% (Appendix D). While the Dry Lake study site showed similar soil affinities with the Lassics lupine habitat based on the dendrogram cluster analysis, the presence of another *Lupinus* species reduces the compatibility of this site due to the risk of hybridization. Additionally, Dry Lake had a soil pH of 5.9 and sand content of 70%, falling below the Lassics lupine ranges for both characteristics (Appendix D). The Bug Creek Butte study site was difficult to access and soil analyses did not show ultramafic influenced soils, making it less ideal for planting trials. While Bug Creek Butte did have the highest sand content of any study site with 75% composition, it had the most acidic qualities of all four study sites with a pH of 5.4 (Appendix D).

While four study sites were explored for this research, additional sites were deemed as climatically and geologically optimal in Del Norte, Siskiyou, and Trinity Counties (Figure 9). High elevation sites could be ground-truthed to determine their feasibility as climate refugia for the Lassics lupine, and further assessed through deployment of affordable iButton data loggers to collect baseline soil temperature data. These data could also elucidate snow melt based on decreasing temperatures in the winter to near zero °C and rising temperatures in spring months, therefore characterizing snowpack duration and persistence. Noteworthy areas that could be explored include numerous relatively accessible sites in the higher elevations of the Smith River National Recreation Area of SRNF, and adjacent montane serpentine habitats.

Future research could collect additional soil temperature data and soil samples, as well as insolation and soil moisture using data loggers with higher IPX ratings. This study was limited to just eight months of microhabitat data collection, and did not capture the seasonal variations and temperature extremes that may be present within each study site. High summer temperatures may lead to mortality with *ex-situ* Lassics lupine planting trials. Soil samples could be taken along ridgelines and varying levels of the slope to evaluate nuances in soil elements and characteristics. Insolation data could elucidate the ambient temperatures while soil moisture data would provide more insight into summer dry-down curves and seasonal soil moisture levels. Additionally, microorganismal communities could be characterized by assessing arbuscular mycorrhizal fungi (AMF) communities within the soil to improve the establishment of seeds or mature plants. These additional microhabitat data can help determine the degree of suitability for each study site, further supporting future field experiments.

Subsequent HSMs for the Lassics lupine could be built to explore outputs based on alternative environmental variables. Important variables for the Lassics lupine include snowpack duration and insolation (Imper 2012). This study did not employ snowpack due to the inability to locate high-quality GIS layers via open-source data repositories; however, this covariate could be created with the support of climatologists and GIS specialists. Similarly, high resolution environmental covariates (<one km^2) could be developed, providing more precision in predicted habitat. While WorldClim insolation was explored as a potential variable, it was highly correlated ($|r|>0.7$) with the other covariates and was not used to build the final model. However, if used in conjunction with other covariates, insolation may be more suitable for building future HSMs for the Lassics lupine. Climate change scenario models could be developed to highlight areas of refugia for the Lassics lupine. These areas could then be assessed via microhabitat data collection and possible future assisted migration trials to prepare for warming future conditions.

This study explored relocation habits for a potential assisted migration plan for the endangered serpentine endemic, the Lassics lupine. It highlights the importance of microhabitat assessment for potential relocation sites, as well as the nuances of building habitat suitability models with small sample sizes and a large AOI. While further evaluation of the study sites explored within this study are needed prior to field validation of the model, preliminary data has been gathered in habitats that surround the current Lassics Mountains that provide a foundation for future research.

REFERENCES

Alexander E. B. 2008. A soil survey of serpentine landscapes in the Lassics area: soils and geoecology for Six Rivers National Forest. Unpublished report for USFS Six Rivers National Forest, Region 5, California.

Alexander E. B. 2011. Serpentine soils and why they limit plant survival and growth. Fremontia 38: 28–31.

Anderson R. P., Gonzalez I. 2011. Species-specific tuning increases robustness to sampling bias in models of species distributions: An implementation with Maxent. Ecological Modelling 222: 2796-2811.

Anderson M. J., Walsh D. C. I. 2013. PERMANOVA, ANOSIM, and the Mantel test in the face of heterogeneous dispersions: what null hypothesis are you testing? Ecological Monographs 83: 557-574.

Argüelles-Moyao A., Galicia L. 2023. Assisted migration and plant invasion: importance of belowground ecology in conifer forest tree ecosystems. Canadian Journal of Forest Research 1-46.

Baldwin B. G., Goldman D. H., Keil D. J., Patterson R., Rosatti T. J., Wilken D. H. 2012. The Jepson manual: vascular plants of California. 2nd edition. University of California Press, Berkeley, CA.

Bean W. T., Stafford R., Brashares J. S. 2012. The effects of small sample size and sample bias on threshold selection and accuracy assessment of species distribution models. Ecography 35: 250-258.

Burnham K. P., Anderson D. R. 2004. Multimodel inference understanding AIC and BIC in model selection. Sociological Methods & Research 33: 261-304.

Brady K. U., Kruckeberg A. R., Bradshaw Jr. H. D. 2005. Evolutionary ecology of plant adaptation to serpentine soils. Annual Review of Ecology, Evolution, and Systematics 36: 243–266.

Bradie J., Leung B. 2017. A quantitative synthesis of the importance of variables used in MaxEnt species distribution models. Journal of Biogeography 44: 1344-1361.

Calflora. 2024. Berkeley, California: The Calflora Database.

California Department of Conservation. 2015. Geologic Map of California.

California Department of Fish and Wildlife, Natural Diversity Database, BIOS. 2020. California Department of Fish and Wildlife, Biogeographic Data Branch, Sacramento, CA.

California Department of Fish and Wildlife. 2018. Protocol for Surveying and Evaluating Impacts to Special Status Native Plant Populations and Natural Communities. State of California.

California Native Plant Society, Rare Plant Program. 2020. Inventory of rare and endangered plants of California (online edition, v8-03 0.39). California Native Plant Society, Sacramento, CA.

Cate E. B. 2016. Consumer movement among successional communities in relation to the rare, endemic plant Lassics lupine (*Lupinus constancei*). Master's Thesis, Humboldt State University, Arcata, California.

Carothers S. K. 2008. Lassics lupine vegetation study. Unpublished report to the US Fish and Wildlife Service, Arcata Field Office, Region 2, California.

Chen I. C., Hill J. K., Ohlemöller R., Roy D. B., Thomas C. D. 2011. Rapid range shifts of species associated with high levels of climate warming. Science 333: 1024-1026.

Cincotta R. P., Wisnewski J., Engelman R. 2000. Human population in the biodiversity hotspots. Nature 404: 990–992.

Conservation International. 2021. What are biodiversity hotspots? Conservation International [accessed 2021 Jan 17]. http://www.conservation.org

Deb J. C., Furze S., MacLean D. A. 2023. Modeling the distribution of Acadian vascular rare plant species under future climate scenarios. Plant Ecology 224: 47-57.

Department of the Interior Fish and Wildlife Service. Endangered and threatened wildlife and plants; endangered species status for Lassics lupine and designation of critical habitat. Federal Register 88: 69074. October 5, 2023.

Dirnböck T., Essl F., Rabitsch W. 2011. Disproportional risk for habitat loss of high-altitude endemic species under climate change. Global Change Biology 17: 990–996.

Dormann C. F., Elith J., Bacher S., Buchmann C., Gudrun C., Carré G., Marquéz J. R. G., Gruber B., Lafourcade B., Leitão P. J., Münkemüller T., McClean C., Osborne P. E., Reineking B., Schröder B., Skidmore A. K., Zurell D., Lautenbach S. 2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. Ecography 36: 27-46.

Draper D., Marques I., Iriondo J. M. 2019. Species distribution models with field validation, a key approach for successful selection of receptor sites in conservation translocations. Global Ecology and Conservation 19: e00653.

Elith J., Phillips S. J., Hastie T., Dudík M., Chee Y. E., Yates C. J. 2011. A statistical explanation of MaxEnt for ecologists. Diversity Distributions 17: 43-57.

Elsen P., Tingley M. 2015. Global mountain topography and the fate of montane species under climate change. Nature Climate Change 5.

Esri Inc. 2022. ArcGIS Pro (Version 3.0.2). Esri Inc. https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview

Fazey I., Fischer J. 2009. Assisted migration is a techno-fix. Trends in Ecology and Evolution 24: 475.

Federov N., Kutueva A., Muldashev A., Mikhaylenko O., Martynenko V., Fedorova Y. 2021. Prediction of habitat suitability for *Patrinia sibirica* Juss. in the southern Urals. Scientific Reports 11: 19606.

Fick S. E., Hijmans R. J. 2017. WorldClim 2: new 1km spatial resolution climate surfaces for global land areas. International Journal of Climatology 37: 4302-4315.

Graham J., Kimble M. 2018. Visualizing uncertainty in habitat suitability models with the hyper-envelope modeling interface, version 2. Ecology and Evolution 9: 251-264.

Guerrant E. O., Kaye T. N. 2007. Reintroduction of rare and endangered plants: common factors, questions and approaches. Australian Journal of Botany 55: 362–370.

Gogol-Prokurat M. 2011. Predicting habitat suitability for rare plants at local spatial scales using species distribution model. Ecological Applications 21: 33-47.

Hällfors M. H., Aikio S., Fronzek S., Hellmann J. J., Ryttäri T., Heikkinen R. K. 2016. Assessing the need and potential of assisted migration using species distribution models. Biological Conservation 196: 60-68.

Hammer Ø., Harper D. A. T., Ryan P. D. 2001. PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4: 1-9.

Harrison S., Southard R. J., Day H. W., Spasojevic M. J., Bullard V. 2011. Climate change and the future of California's serpentine flora: using geologic and soil information to improve conservation strategies. Mission Kearney Foundation of Soil Science Final Report, 2009022.

Harrison S., Viers J. H., Thorne J. H., Grace J. B. 2008. Favorable environments and the persistence of naturally rare species. Conservation Letters 1: 65-74.

Horton J. D. 2017. The State Geologic Map Compilation (SGMC) geodatabase of the conterminous United States (ver. 1.1, August 2017): U.S. Geological Survey data release.

Hufford K., Mazer S. 2003. Plant ecotypes: genetic differentiation in the age of ecological restoration. Trends in Ecology & Evolution 18: 147–155.

Imper D. 2016. Petition to the state of California fish and wildlife commission to list the Lassics lupine (*Lupinus constancei*) as endangered under the California endangered species act.

Imper D. 2012. DRAFT revised data summary and conclusions Lassics lupine (*Lupinus constancei*) soils and climate study: The Lassics, Six Rivers National Forest. Arcata, CA: United States Fish and Wildlife Service.

iNaturalist. 2024. Available from https://www.inaturalist.org. [accessed 2024 Jan 01]

Jain A. K., Chandrasekaran B. 1982. 39 dimensionality and sample size considerations in pattern recognition practice. Handbook of Statistics 2: 835-855.

Jepson Flora Project (eds.) 2024. Jepson eFlora. [accessed 2024 Jan 27]. http://ucjeps.berkeley.edu/eflora/

Jolliffe I. T., Allen O. B., Christie B. R. 1989. Comparison of variety means using cluster analysis and dendrograms. Experimental Agriculture 25: 259-269.

Kierczak J., Pietranik A, Pędziwiatr A. 2021. Ultramafic geoecosystems as a natural source of Ni, Cr, and Co to the environment: A review. Science of the Total Environment 755: 142620.

Kruckeberg A. R. 1992. Plant life of western North American ultramafics. In: Roberts B. A., Proctor J., editors. The Ecology of Areas with Serpentinized Rocks. Dordrecht: Springer Netherlands; p. 31–73.

Kurkjian H. M., Carothers S. K., Jules E. S. 2017. Seed predation has the potential to drive a rare plant to extinction. Nuñez M, editor. Journal of Applied Ecology 54: 862–871.

Lamprecht A., Semenchuk P. R., Steinbauer K., Winkler M., Pauli H. 2018. Climate change leads to accelerated transformation of high-elevation vegetation in the central Alps. New Phytologist 220: 447–59.

Lannuzel G., Balmot J., Dubos N., Thibault M., Fogliani B. 2021. High-resolution topographic variables accurately predict the distribution of rare plant species for conservation area selection in a narrow-endemism hotspot in New Caledonia. Biodiversity and Conservation 30: 963–990.

Lobo J. M., Jimenez-Valverde A., Real R. 2008. AUC: a misleading measure of the performance of predictive distribution models. Global Ecology and Biogeography 17: 145-151.

Loarie S. R., Carter B. E., Hayhoe K., McMahon S., Moe R., Knight C. A., Ackerly D. D. 2008. Climate change and the future of California's endemic flora. PLOS ONE 3: 2502.

Maschinski, J., Wright S. J. 2006. Using ecological theory to plan restorations of the endangered Beach jacquemontia (Convolvulaceae) in fragmented habitats. Journal for Nature Conservation 14: 180–189.

Merow C., Smith M. J., Silander J. A. Jr. 2013. A practical guide to maxent for modeling species' distributions: what it does, and why inputs and settings matter. Ecography 36: 1058-1069.

Morales-Barbero J., Vega-Álvarez J. 2018. Input matters matter: bioclimatic consistency to map more reliable species distribution models. Methods in Ecology and Evolution 10: 212-224.

NatureServe. 2021. Definitions of NatureServe conservation status ranks. Arlington, Virginia. [accessed 2021 Jan 15]. https://www.natureserve.org/

Nelson T. W., Nelson J. P. 1983. Two new species of Leguminosae from serpentine of Humboldt County, California. Brittonia 35: 180–183.

Nomoto H. A., Alexander J. M. 2021. Drivers of local extinction risk in alpine plants under warming climate. Ecology Letters 24: 1157–66.

Phillips S. J. 2010. A brief tutorial on MaxEnt. Lessons in Conservation 3: 108-135.

Phillips S. J., Anderson R. P., Schapire R. E. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling 190: 231-259.

Phillips S. J., Dudík M. 2008. Modeling of species distributions with maxent: new extensions and a comprehensive evaluation. Ecography 31: 161-175.

Phillips S. J., Dudík M., Schapire R. E. 2020. Maxent software for modeling species niches and distributions (Version 3.4.3) [Computer software].

R Core Team. 2021. R: A language and environment for computing. R Foundation for Statistical Computing, Vienna, Austria.

Radosavljevic A., Anderson R. P. 2014. Making better maxent models of species distributions: complexity, overfitting and evaluation. Journal of Biogeography 41: 629-643.

Reibsome E. L. 2022. Forecasting the outcomes of managing a rare endemic plant at its elevational limit under climate change scenarios. Master’s Thesis, Humboldt State University, Arcata, California.

Rodionova O., Kucheryavskiy S., Pomerantsev A. 2021. Efficient tools for principal component analysis of complex data— a tutorial. Chemometrics and Intelligent Laboratory Systems 213: 104304.

Safford H. D., Viers J. H., Harrison S. P. 2005. Serpentine endemism in the California flora: a database of serpentine affinity. Madroño 52: 222–257.

Sen L. K., Shitan M. 2002. The performance of AICc as an order selection criterion in ARMA time series models. Pertanika Journal of Science & Technology 10: 25-33.

Shcheglovitova M., Anderson R. P. 2013. Estimating optimal complexity for ecological niche models: a jackknife approach for species with small sample sizes. Ecological Modelling 269: 9-17.

Shlens J. 2014. A Tutorial on Principal Component Analysis. Google Research, Mountain View, CA.

Simberloff D. 2005. The politics of assessing risk for biological invasions: the USA as a case study. Trends in Ecology and Evolution 20: 216–222.

Skinner C. N., Taylor A. H., Agee J. K. 2006. Klamath Mountains Bioregion. In: Sugihara N. G., van Wagtendonk J. W., Fites-Kaufmann J., Shaffer K. E., Thode A. E., editors. Fire in California's ecosystems. University of California Press, Berkeley; p. 170-194.

Tojibaev K., Beshko N., Volis S. 2019. Translocation of *Otostegia bucharica*, a highly threatened narrowly distributed relict shrub. Plant Diversity 41: 105-108.

Van der Lee G. E. M., Van der Molen D. T., Van den Boogard H. F. P., Van der Klis H. 2006. Uncertainty analysis of a spatial habitat suitability model and implications for ecological management of water bodies. Landscape Ecology 21: 1019-1032.

Vitt P., Havens K., Hoegh-Guldberg O. 2009. Assisted migration: part of an integrated conservation strategy. Trends in Ecology & Evolution 24: 473–474.

Vitt P., Havens K., Kramer A. T., Sollenberger D., Yates E. 2010. Assisted migration of plants: changes in latitudes, changes in attitudes. Biological Conservation 143: 18–27.

Wang Q., Lu Y., Zhang X., Hahn J. 2021. Region of interest selection for functional features. Neurocomputing 422: 235-244.

Warren D. L., Seifert S. N. 2011. Ecological niche modeling in maxent: the importance of model complexity and the performance of model selection criteria. Ecological Applications 21: 335–342.

Whittaker R. H. 1961. Vegetation history of the Pacific coast states and the "central" significance of the Klamath region. Madroño 16: 5-23.

Wisz M., Guisan A. 2009. Do pseudo-absence selection strategies influence species distribution models and their predictions? An information-theoretic approach based on simulated data. BMC Ecology 9: 1-13.

Wu X. B., Smeins F. E. 2000. Multiple-scale habitat modeling approach for rare plant conservation. Landscape and Urban Planning 51: 11-28.

TABLES

Table 1. Environmental variables obtained from WorldClim version 2 that were used to build the Habitat Suitability Model. Temperature data are in °C * 10 and precipitation data are in mm. All variables are raster files at one km^2 resolution.

Abbreviation	Description
BIO2	Mean Diurnal Range (Mean of monthly (max temp – min temp))
BIO3	Isothermality (BIO2/BIO7) (×100)
BIO4	Temperature Seasonality (standard deviation ×100)
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
SOL07	Insolation (Solar Radiation) of Month of July

Table 2. Output from the 18 MaxEnt model runs to evaluate performance based on AUC and AICc. Feature class abbreviations are as follows: L = linear, LQ = linear & quadratic, auto = linear, quadratic, product, and hinge; RM = regularization multiplier. Each model run was characterized by two WorldClim variables, 100 replicates, and a maximum iteration of 5000 to allow for convergence of the model.

Feature Classes	RM	Number of Parameters	Loglikelihood	AUC	AICc	Δ AICc
L	1	6	-118	0.9844	227	0
L	2	6	-118	0.9844	228	1
L	5	6	-120	0.9845	231	4
L	10	6	-123	0.9840	237	10
L	15	6	-126	0.9801	244	17
L	20	6	-130	0.9689	251	24
LQ	1	6	-118	0.9844	227	0
LQ	2	6	-118	0.9844	228	1
LQ	5	6	-120	0.9845	231	4
LQ	10	6	-123	0.9840	237	10
LQ	15	6	-126	0.9801	244	17
LQ	20	6	-130	0.9689	251	24
auto	1	6	-118	0.9844	227	0
auto	2	6	-118	0.9844	228	1
auto	5	6	-120	0.9845	231	4
auto	10	6	-123	0.9840	237	10
auto	15	6	-126	0.9801	244	17
auto	20	6	-130	0.9689	251	24

Table 3. For all uncertainty testing conducted on both response and explanatory variables, the Monte Carlo MaxEnt tool in BlueSpray was used. Noise injections were tailored to the covariates based on their true mean and standard deviation values. Fifty iterations were done for each model run with six parameters each. The feature classes used for all model runs were linear - quadratic with a regularization multiplier of five to align with the final HSM selected for further evaluation. Abbreviations: BIO11: mean temperature of the coldest quarter of the year; BIO16: precipitation of the wettest quarter of the year.

Variable	Range	True Mean	True Standard deviation	Testing Mean	Testing Standard deviation	Loglikelihood	AUC	AICc	Δ AICc
BIO11	-9 - 10	4	3	4	0	-120	0.9845	231	4
					3	-129	0.9456	249	22
					6	-129	0.9456	249	22
BIO16	100 - 1100	559	216	559	0	-120	0.9845	231	4
					229	-150	0.6752	292	65
					459	-151	0.6147	294	67

Table 4. Output from the PERMANOVA for the soil temperature data from the four study sites and the two Lassics lupine demographic monitoring transects, the Saddle and Red Lassic. The permutation was unrestricted with 999 iterations; the distance method used was Euclidean; and the adonis2( ) function was used to compute the test statistic using the *vegan* package in R 4.1.1.

	Df	SumOfSqs	R^2	F	Pr(>F)
North Saddle	1	70681	0.576	-8.90E+18	1
South Saddle	1	13620	0.111	-1.72E+18	1
Red Lassic	1	4765	0.039	-6.00E+17	1
Black Rock 1	1	12145	0.099	-1.53E+18	1
Black Rock 2	1	1729	0.014	-2.18E+17	1
Bug Creek Butte 1	1	885	0.007	-1.11E+17	1
Bug Creek Butte 2	1	251	0.002	-3.16E+16	1
Dry Lake 1	1	404	0.003	-5.09E+16	1
Dry Lake 2	1	492	0.004	-6.20E+16	1
Red Mountain 1	1	1282	0.010	-1.62E+17	1
Red Mountain 2	1	40	<0.001	-5.01E+15	1
Residual	240	0	0		
Total	252	122787	1		

Table 5. Plant species observed during floristic surveys within each of the four study sites encompassing 0.4 ha (1 ac) surrounding the data loggers. Flora from the Lassics lupine habitat obtained from personal knowledge, iNaturalist, Calflora, and Jepson eflora in habitat adjacent to monitoring transects within 0.4 ha (1 ac).

Scientific Name	Bug Creek Butte	Black Rock	Dry Lake	Red Mountain	The Lassics
Achillea millefolium	0	1	0	1	0
Allium campanulatum	0	0	0	1	0
Allium falcifolium	1	1	1	0	1
Allium hoffmanii	0	0	0	0	1
Anisocarpus scabridus	1	0	0	0	0
Aphyllon purpureum	1	0	0	0	0
Astragalus purshii var. lectulus	1	0	0	0	0
Boechera serpenticola	0	0	0	1	0
Calocedrus decurrens	1	1	1	0	1
Calochortus tolmiei	1	1	0	0	0
Chorizanthe membranacea	0	0	0	1	0
Cirsium cymosum car. Cymosum	0	0	0	1	0
Claytonia saxosa	1	0	0	0	1
Collomia tracyi	0	0	1	1	1
Crepis pleurocarpa	1	0	1	1	1
Diplacus nanus	0	0	0	1	1
Eriophyllum lanatum	1	1	0	1	0
Erythronium californicum	0	1	1	0	0
Fritillaria purdyi	1	1	0	0	0
Hieracium albiflorum	0	1	1	0	0
Horkelia tridentata var. flavescens	1	0	0	0	0
Lomatium californicum	1	1	0	1	0
Lomatium macrocarpum	1	1	1	1	1
Lupinus lepidus var. lobbii	0	0	1	0	0
Penstemon purpusii	1	1	1	1	1
Phlox diffusa	1	1	0	1	1
Phoenicaulis cheiranthoides	1	0	0	0	0
Pinus jeffreyi	0	1	1	1	1
Pyrola picta	0	0	1	0	0
Scutellaria antirrhinoides	0	0	0	1	1
Sedum flavidum	1	0	0	1	1
Streptanthus tortuosus	1	0	0	1	1

FIGURES

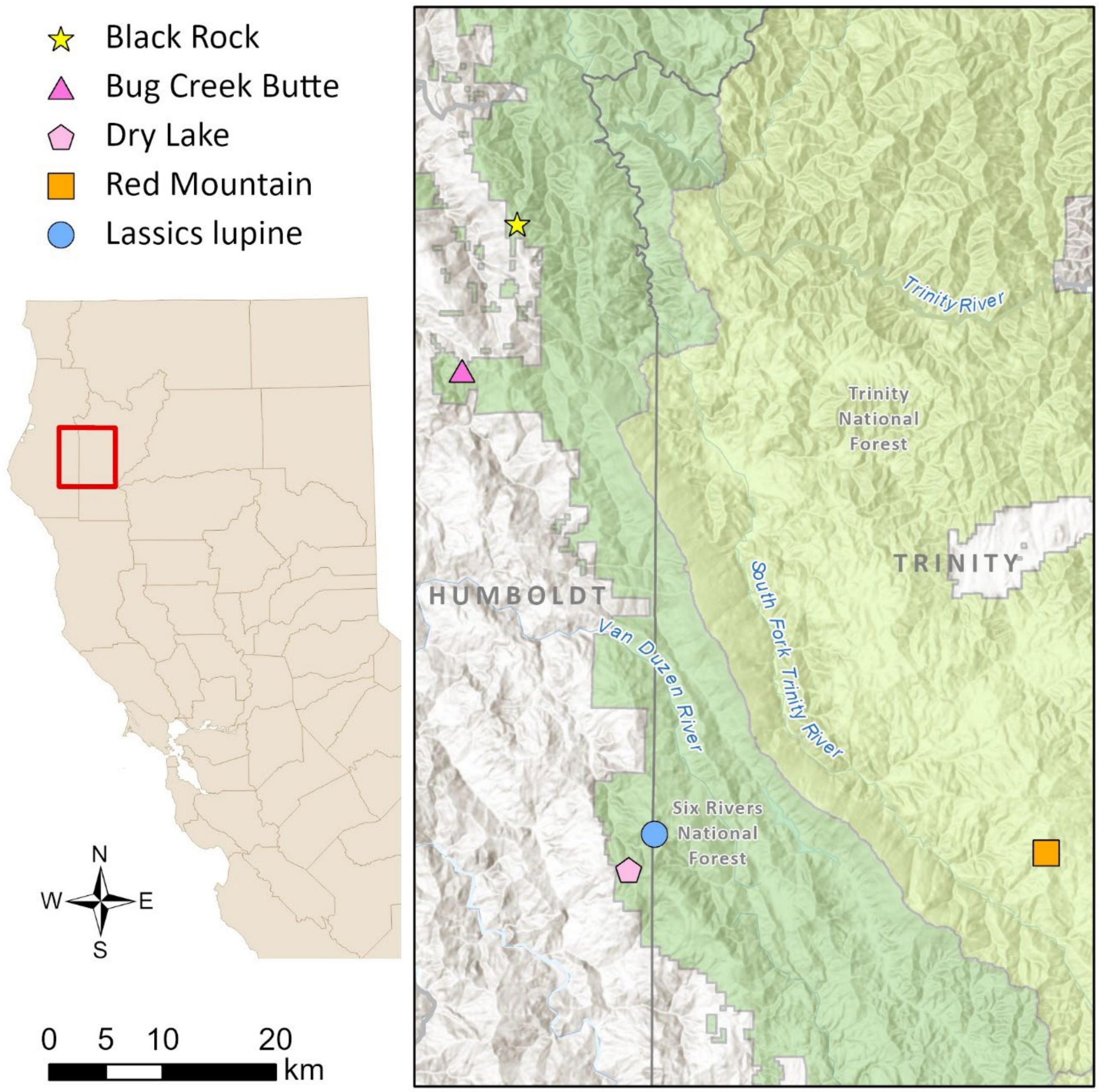


Figure 1. Location of the four study sites derived from the HSM alongside the Lassics lupine habitat in Humboldt and Trinity Counties, California. The red bounding box within the location map on the left indicates the area of interest within Humboldt and Trinity Counties, shown in detail on the topographic map on the right. Credit layers: USDA, USFS, USFWS, BLM, NPS, Esri, CSP, USGS, NASA, Allchin.

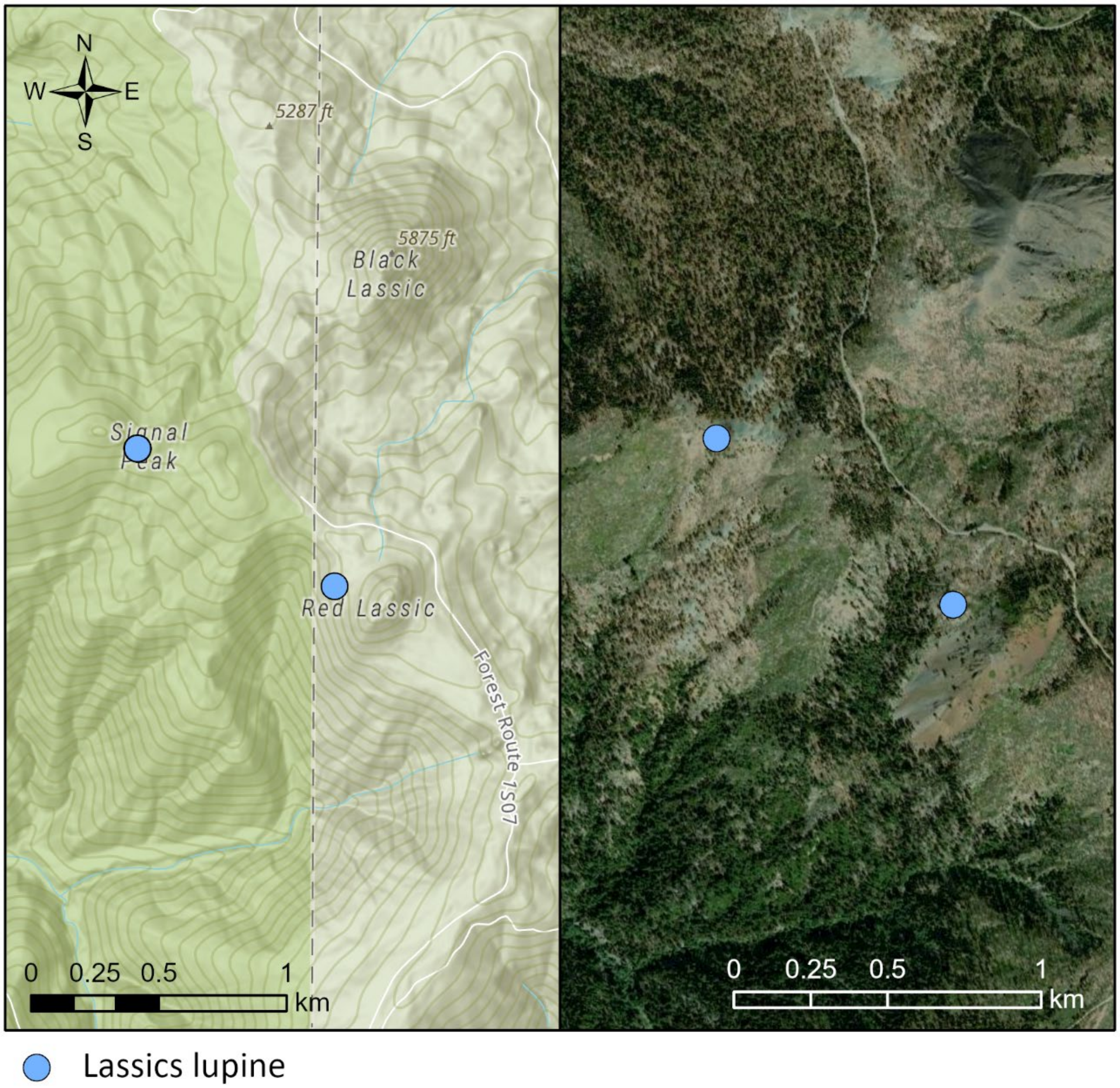


Figure 2. Detail map of the approximate location of the Lassics lupine demographic monitoring transects near Mount Lassic and Red Lassic, in Six Rivers National Forest, showing hill shade and 24 m contour lines alongside aerial imagery. Credit layers: Earthstar Graphics, USDA, USFS, USFWS, BLM, NPS, Esri, CSP, USGS, NASA, Allchin.

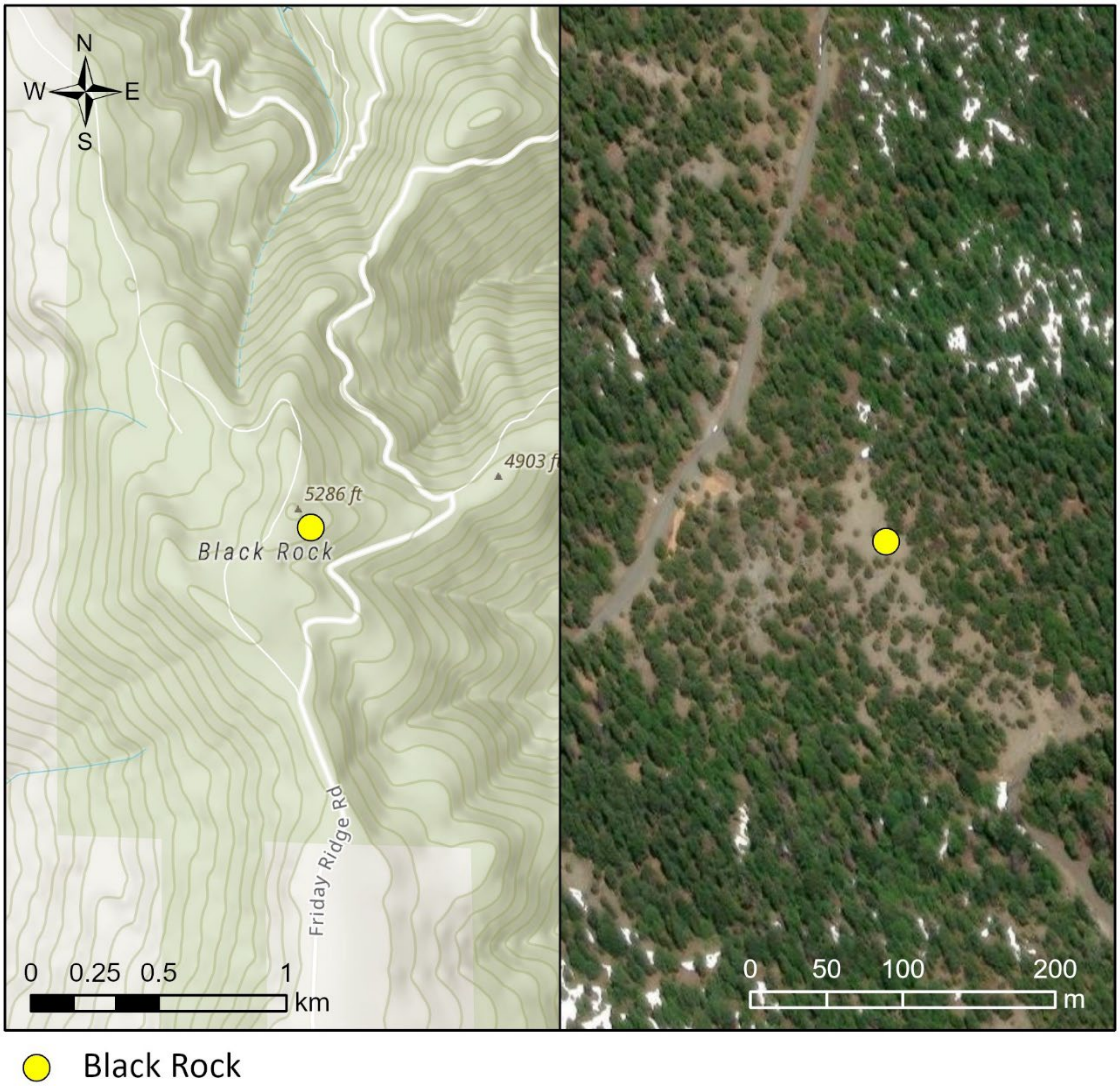


Figure 3. Detail map of the Black Rock study site in Six Rivers National Forest showing hill shade and 24 m contour lines alongside aerial imagery. Credit layers: Earthstar Graphics, USDA, USFS, USFWS, BLM, NPS, Esri, CSP, USGS, NASA, Allchin.

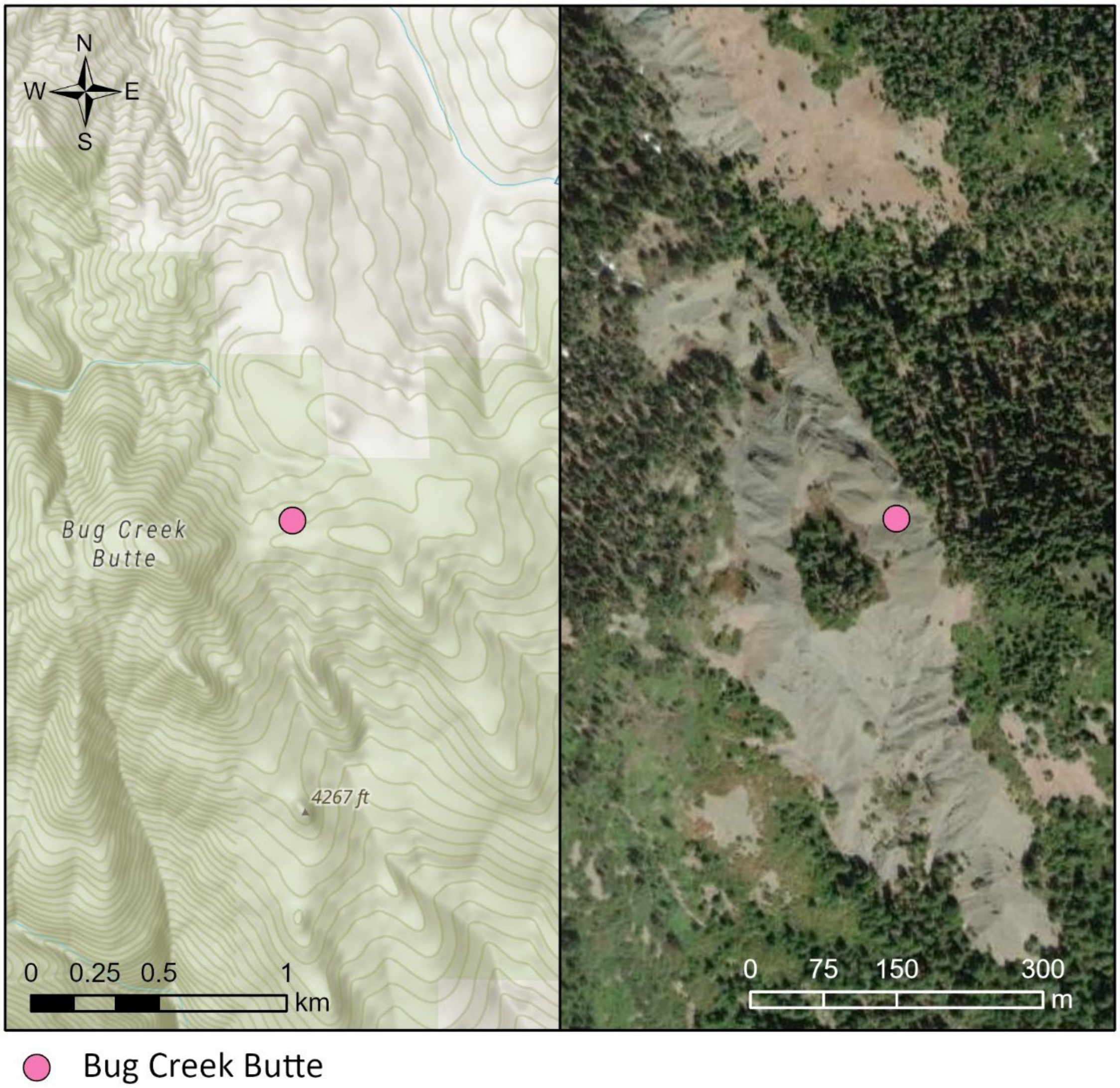


Figure 4. Detail map of the Bug Creek Butte study site in Six Rivers National Forest showing hill shade and 24 m contour lines alongside aerial imagery. Credit layers: Earthstar Graphics, USDA, USFS, USFWS, BLM, NPS, Esri, CSP, USGS, NASA, Allchin.

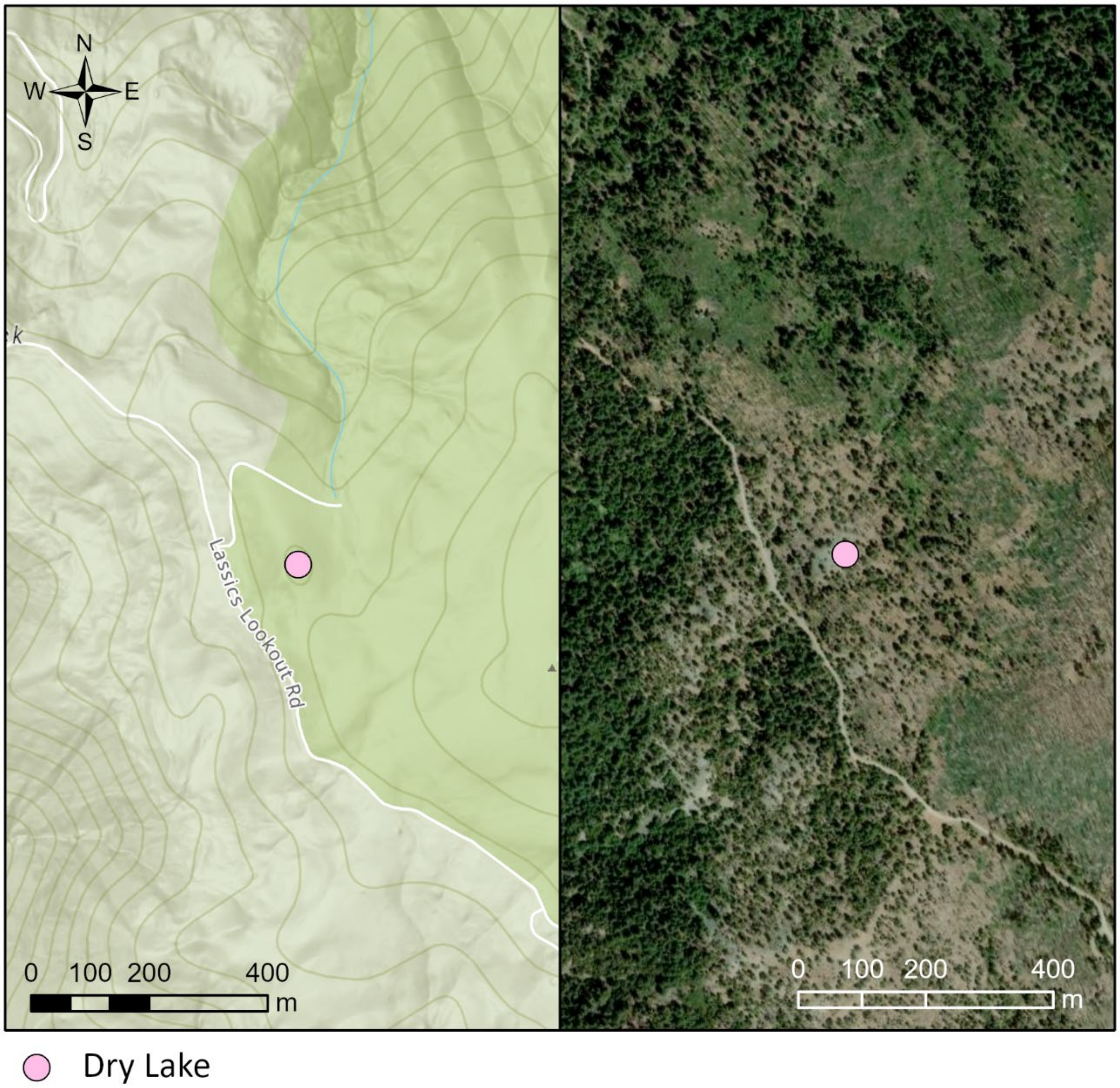


Figure 5. Detail map of the Dry Lake study site in Six Rivers National Forest showing hill shade and 24 m contour lines alongside aerial imagery. Credit layers: Earthstar Graphics, USDA, USFS, USFWS, BLM, NPS, Esri, CSP, USGS, NASA, Allchin.

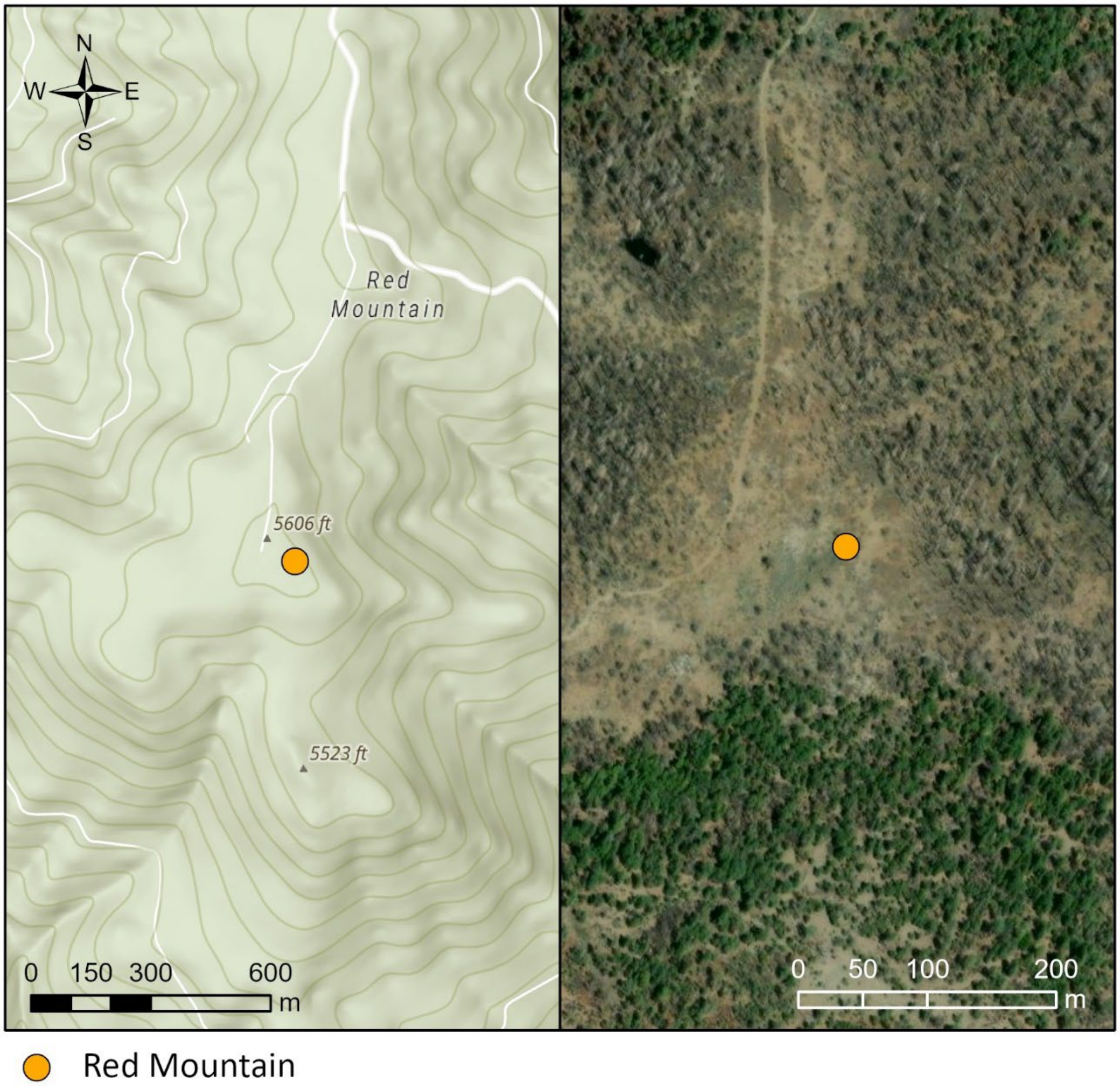


Figure 6. Detail map of the Red Mountain study site in Shasta-Trinity National Forest showing hill shade and 24 m contour lines alongside aerial imagery. Credit layers: Earthstar Graphics, USDA, USFS, USFWS, BLM, NPS, Esri, CSP, USGS, Allchin.

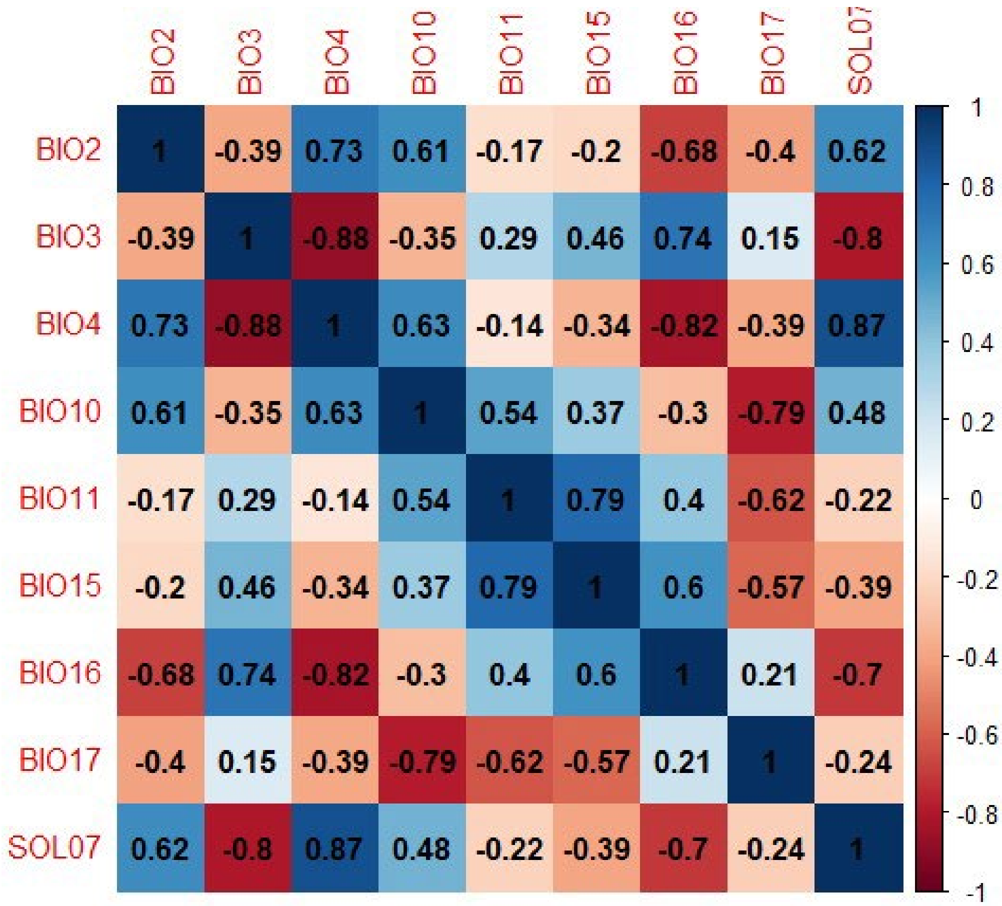


Figure 7. Spearman's correlation plot showing the nine WorldClim covariates selected by expert opinion (D. Imper, pers. comm., 2021). The darker the color and the further the values are from 0, the higher the correlation between covariates; the lighter the color and closer the values are to 0, the lower the correlation between covariates. The covariates used to build the final HSM included mean temperature of the coldest quarter of the year (BIO11) and precipitation of the wettest quarter of the year (BIO16).

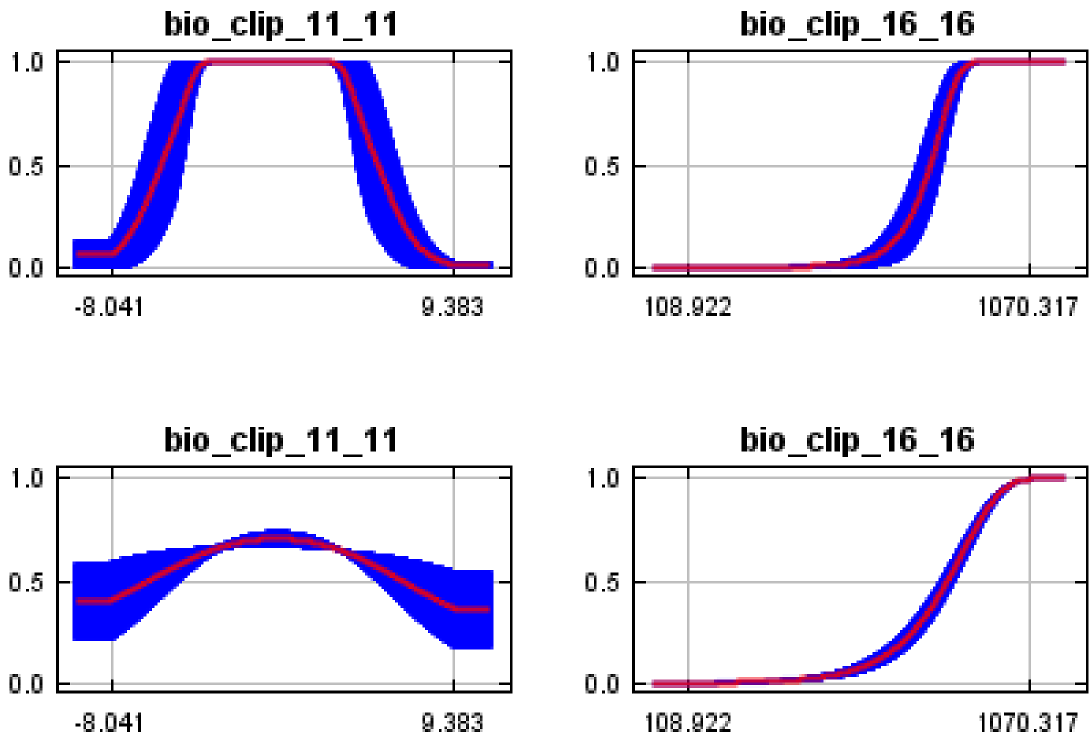


Figure 8. Response curves showing how each WorldClim covariate impacts the prediction within the MaxEnt HSM. The upper two response curves show their marginal response to predicted habitat, while the bottom two response curves indicate how each variable predicted habitat as a univariate model. Covariates used to build the HSM included mean temperature of the coldest quarter of the year (BIO11) and precipitation of the wettest quarter of the year (BIO16).

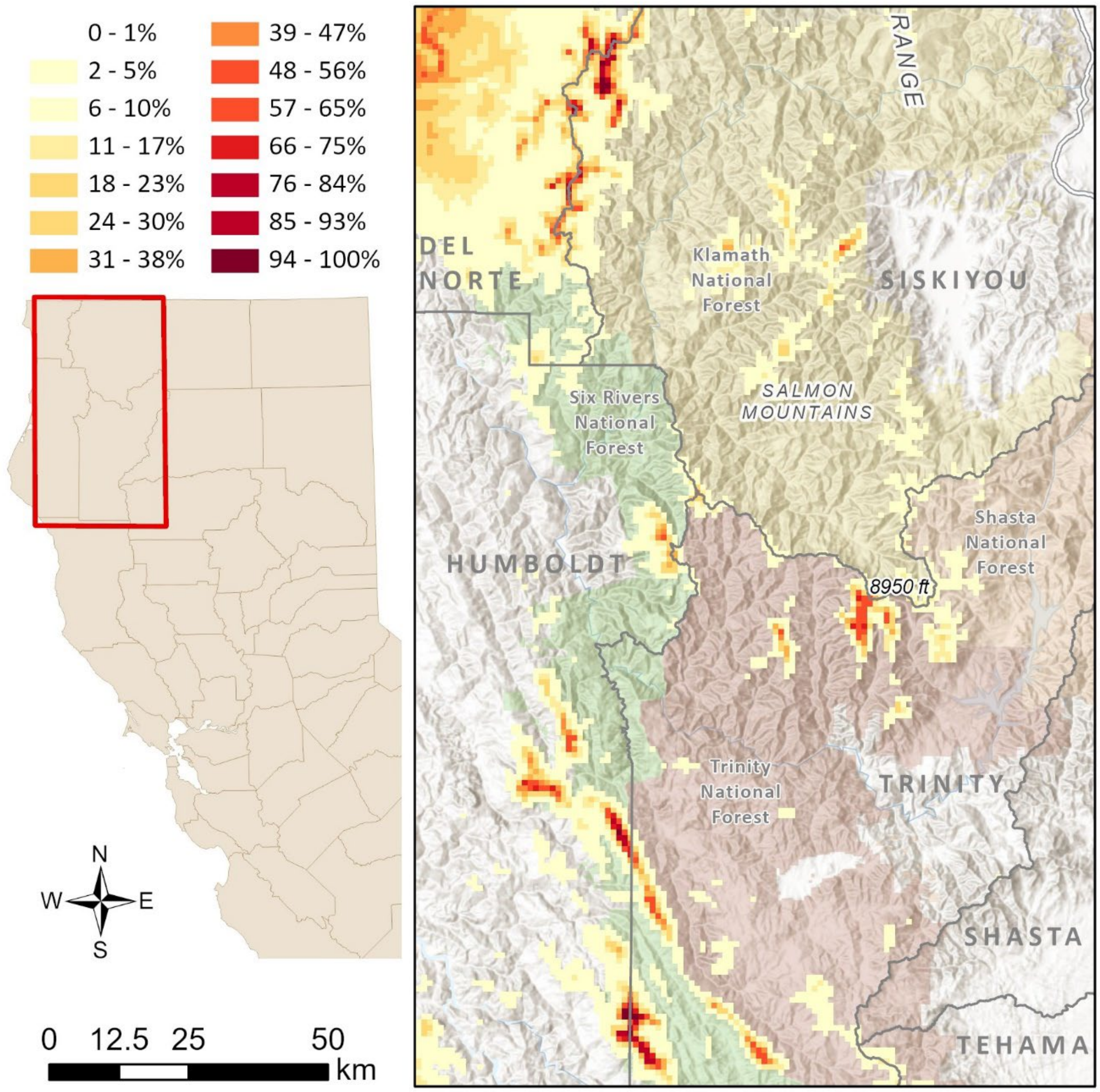
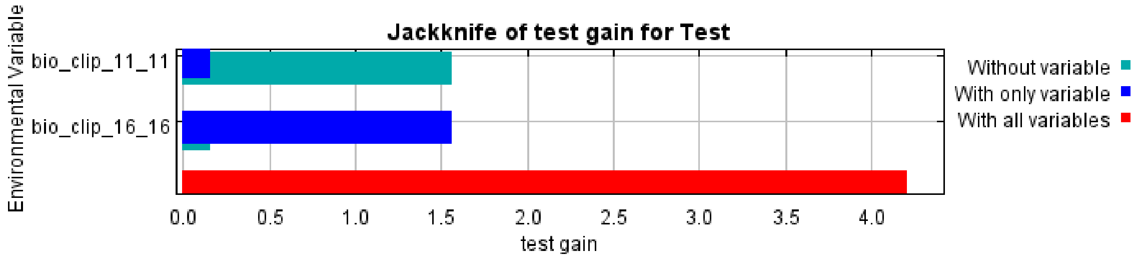


Figure 9. The final MaxEnt habitat suitability model heat map showing suitability values within the study area of northern California spanning Del Norte, Siskiyou, Humboldt, and Trinity Counties. The model was built using two WorldClim covariates as explanatory variables: mean temperature of the coldest quarter of the year (BIO11) and precipitation of the wettest quarter of the year (BIO16). Credit layers: USDA, USFS, USFWS, BLM, NPS, Esri, CSP, USGS, NASA, Allchin.



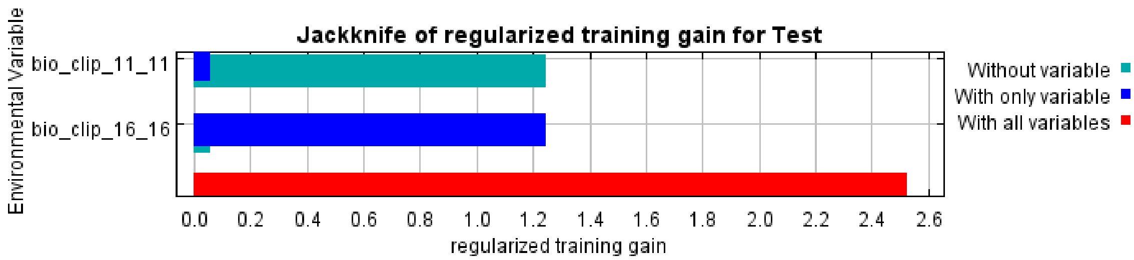


Figure 10. Outputs from the jackknifing of variable importance of both the test gain and training gain conducted within MaxEnt. Training gain indicates data used to train the model were used, while test gain indicates data used to test the model were used to evaluate variable importance. WorldClim covariate BIO16 (bio_clip_16_16) shows the most gain when omitting all other variables for the test gain and also appears to be the most important variable based on the reduced gain when omitted. The same relationship is also present within the training gain of the variables.

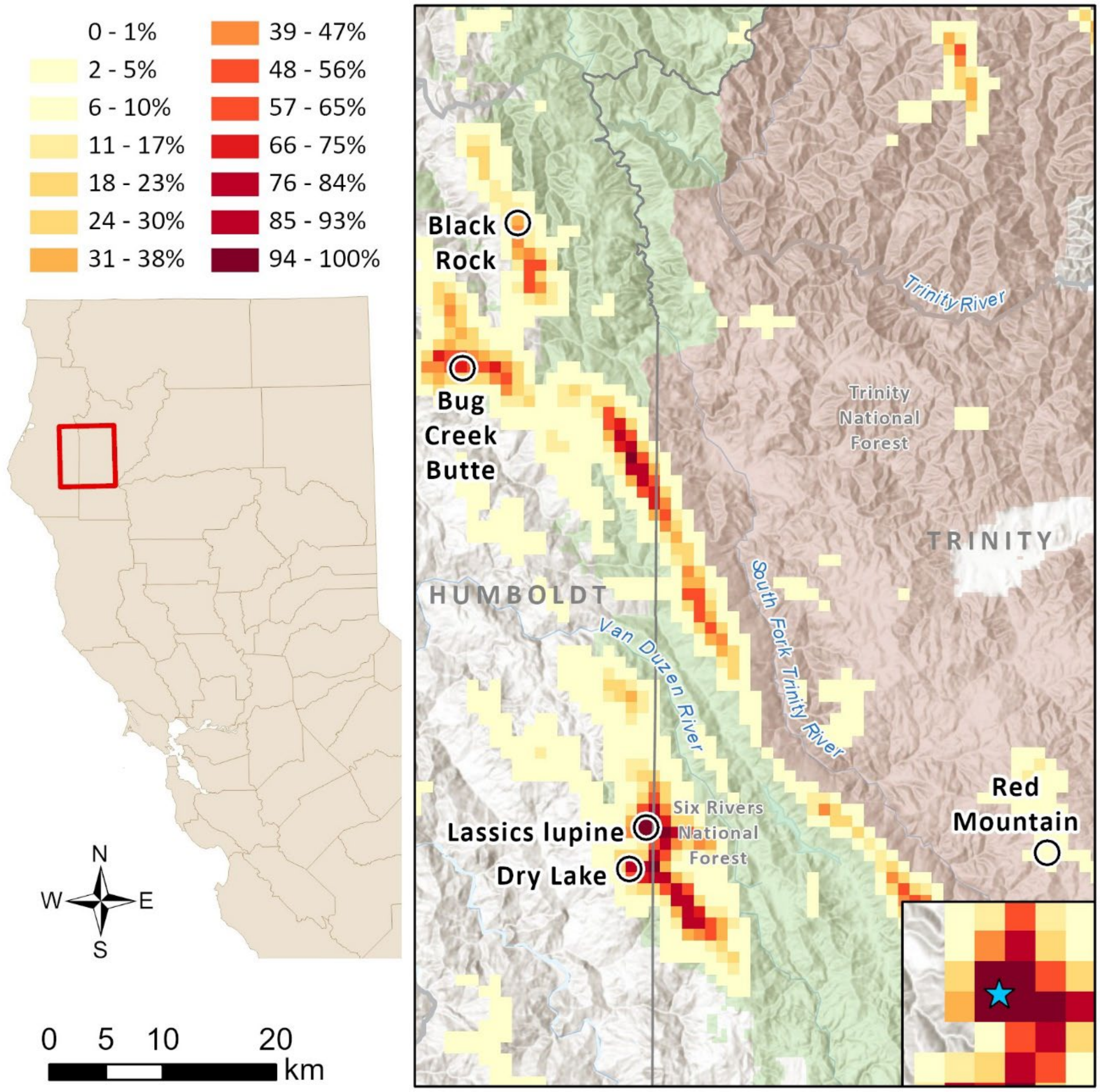


Figure 11. The final MaxEnt habitat suitability model heat map showing suitability values for each study site alongside the Lassics lupine habitat. The model was built using four WorldClim covariates as explanatory variables: mean temperature of the coldest quarter of the year (BIO11) and precipitation of the wettest quarter of the year (BIO16). Blue star indicates location of the Lassics lupine in relation to predicted suitable habitat. Credit layers: USDA, USFS, USFWS, BLM, NPS, Esri, CSP, USGS, NASA, Allchin.

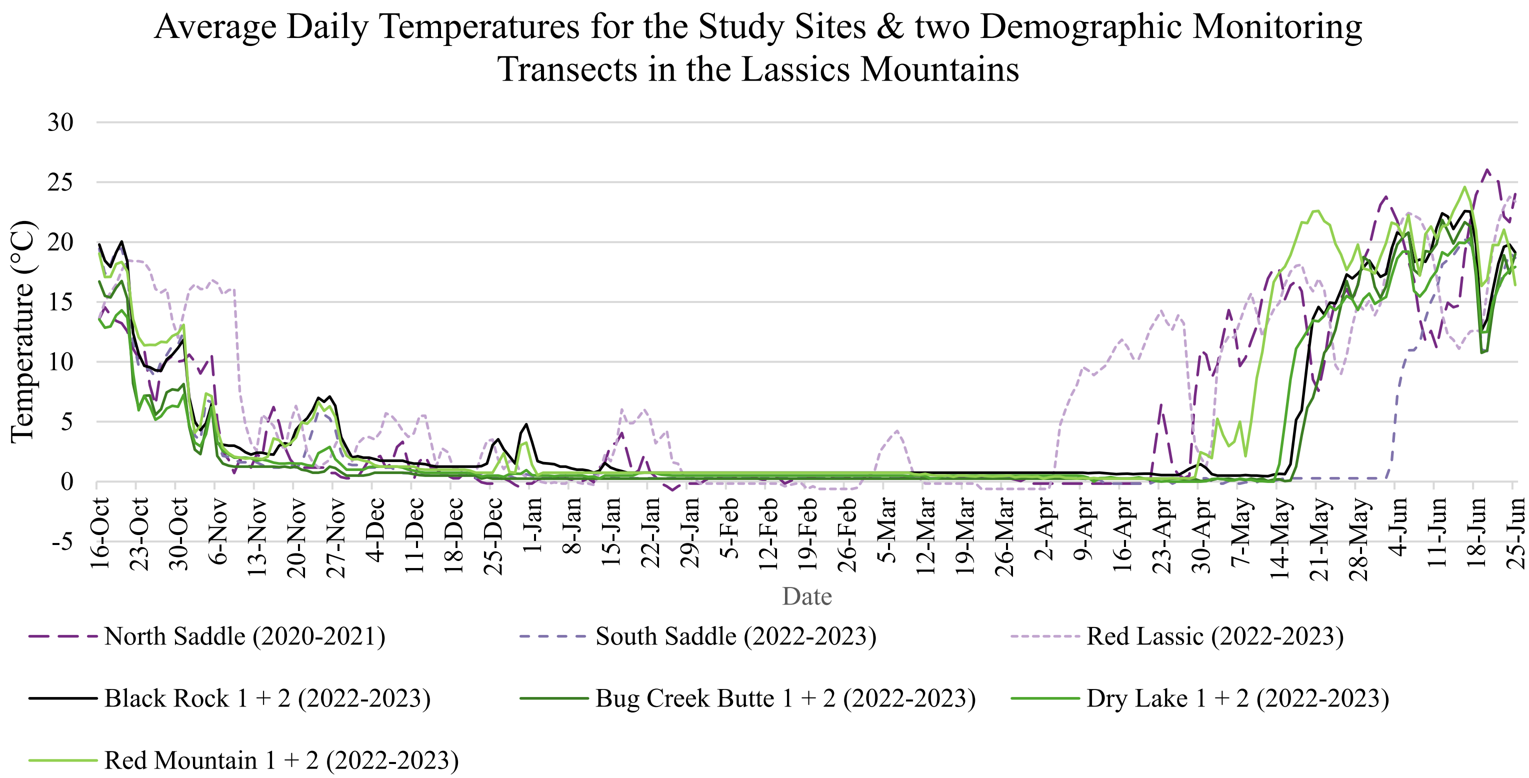


Figure 12. Line graph of the average daily temperatures of the mean iButton values for the four study sites alongside the two most productive demographic monitoring transects (No. & So. Saddle and Red Lassic) from October 16 to June 25. Data obtained for the four study plots, Red Lassic, and the South Saddle were obtained from 2022 - 2023, while the North Saddle data were obtained from 2020 - 2021, to supplement a lack of data collected during 2022 - 2023, and insufficient data collected during 2021 - 2022.

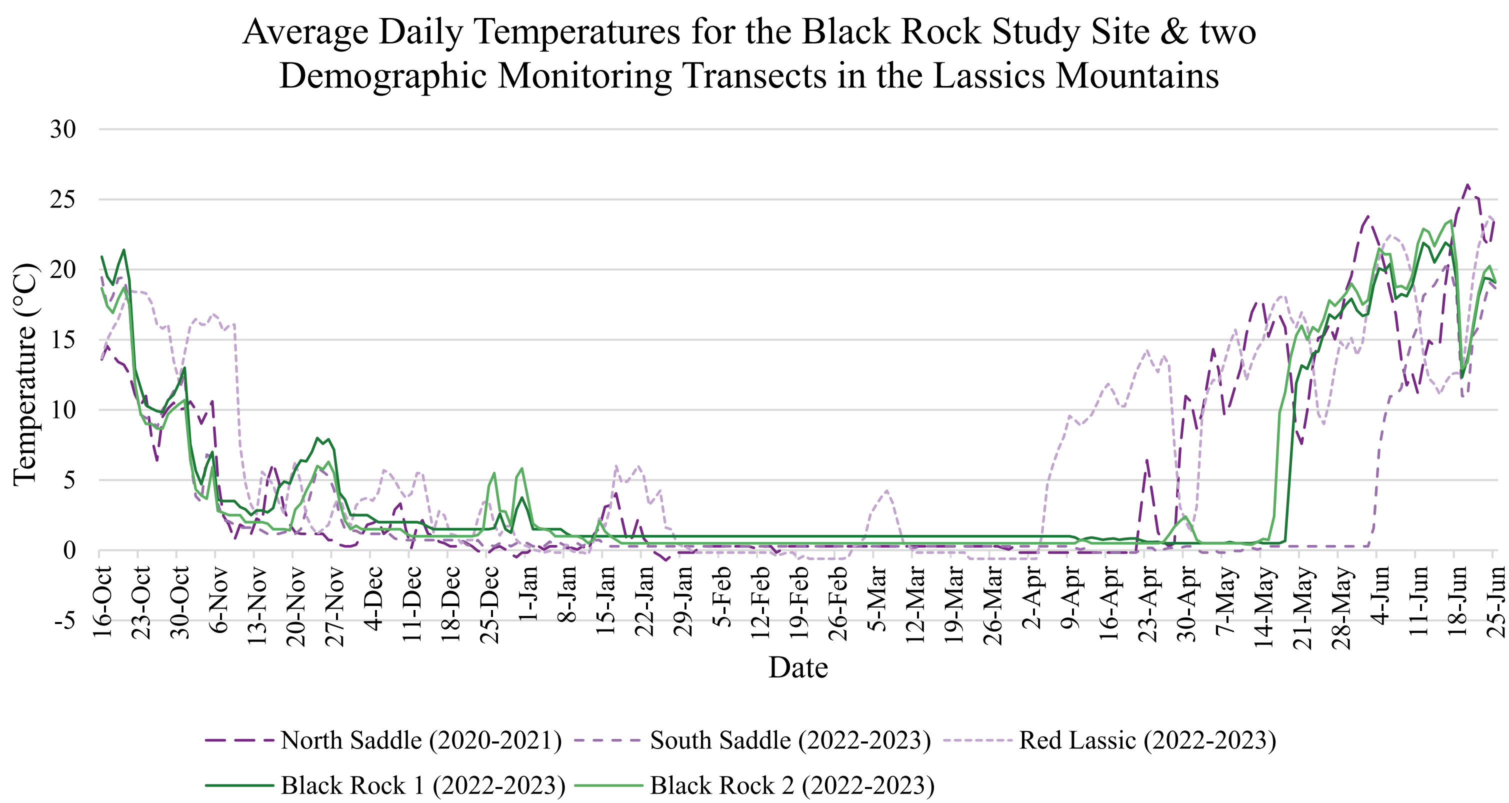


Figure 13. Line graph of the two iButton data loggers for the Black Rock study site alongside the two most productive demographic monitoring transects (North & South Saddle and Red Lassic) during the same time interval between October 16, 2022 - June 25, 2023. Data obtained for the North Saddle were from October 16, 2020 - June 25, 2021, to supplement a lack of data collected during 2022 - 2023, and insufficient data collected during 2021 - 2022.

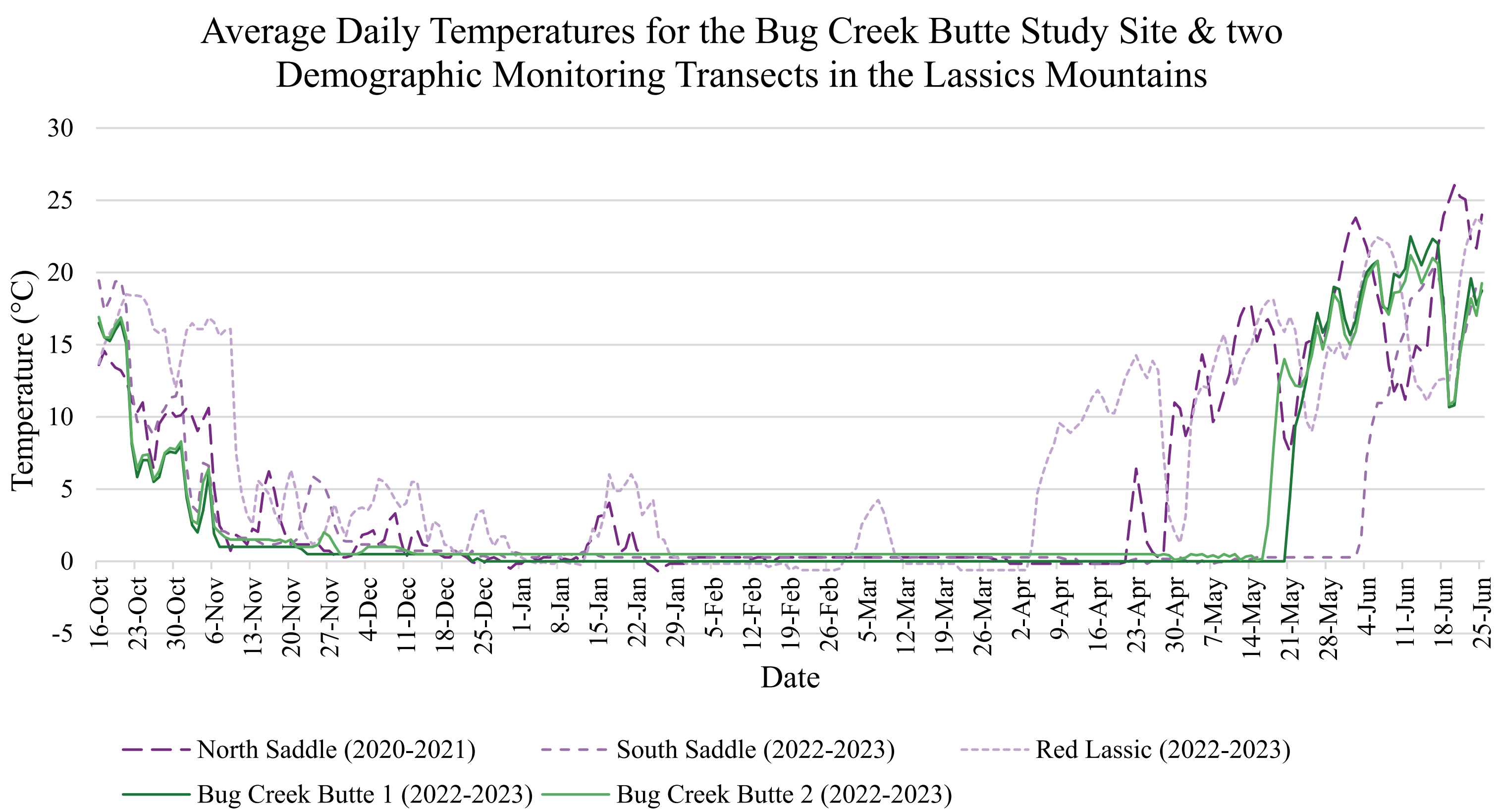


Figure 14. Line graph of the two iButton data loggers for the Bug Creek Butte study site alongside the two most productive demographic monitoring transects (North & South Saddle and Red Lassic) during the same time interval between October 16, 2022 - June 25, 2023. Data obtained for the North Saddle were from October 16, 2020 - June 25, 2021, to supplement a lack of data collected during 2022 - 2023, and insufficient data collected during 2021 - 2022.

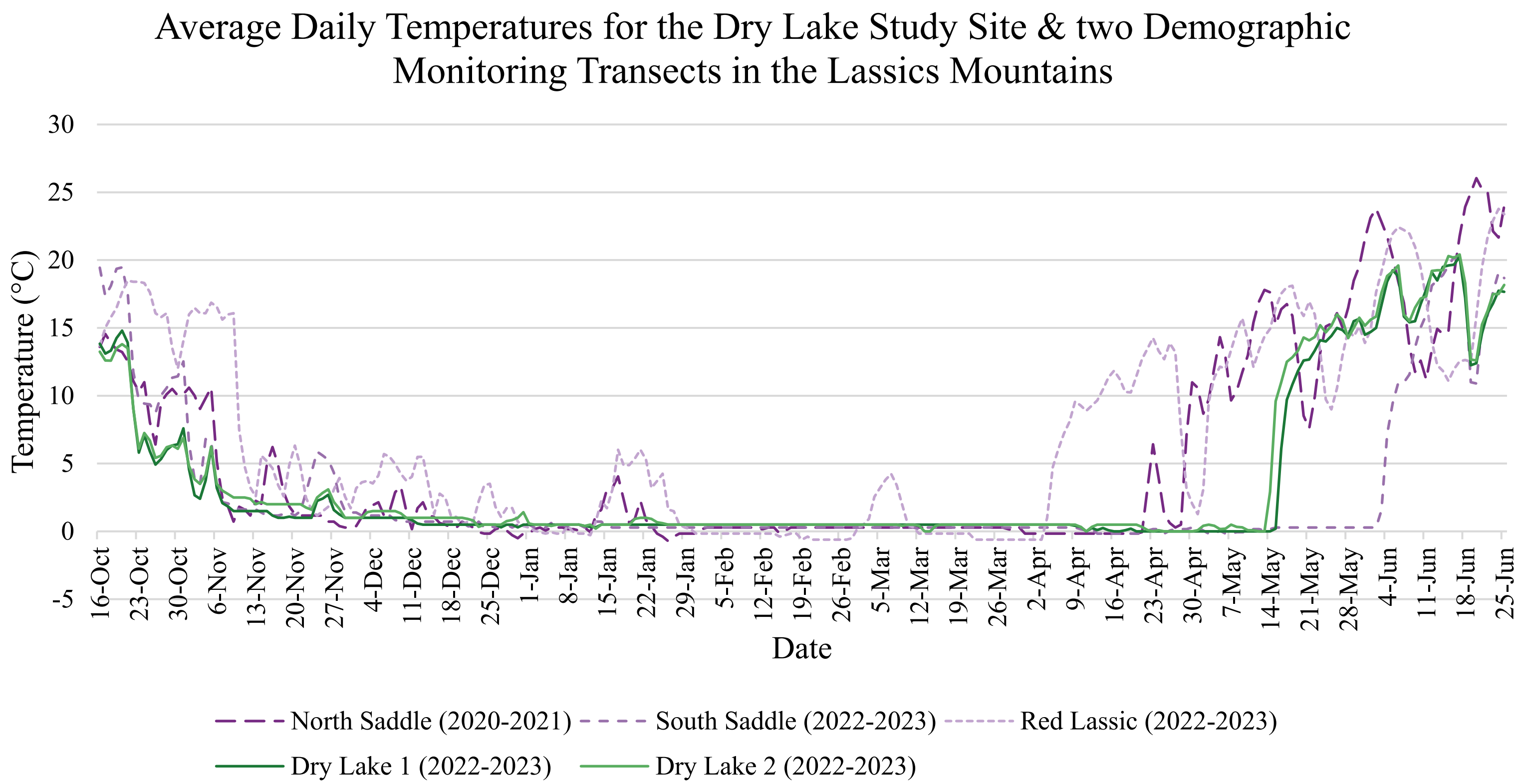


Figure 15. Line graph of the two iButton data loggers for the Dry Lake study site alongside the two most productive demographic monitoring transects (North & South Saddle and Red Lassic) during the same time interval between October 16, 2022 - June 25, 2023. Data obtained for the North Saddle were from October 16, 2020 - June 25, 2021, to supplement a lack of data collected during 2022 - 2023, and insufficient data collected during 2021 - 2022.

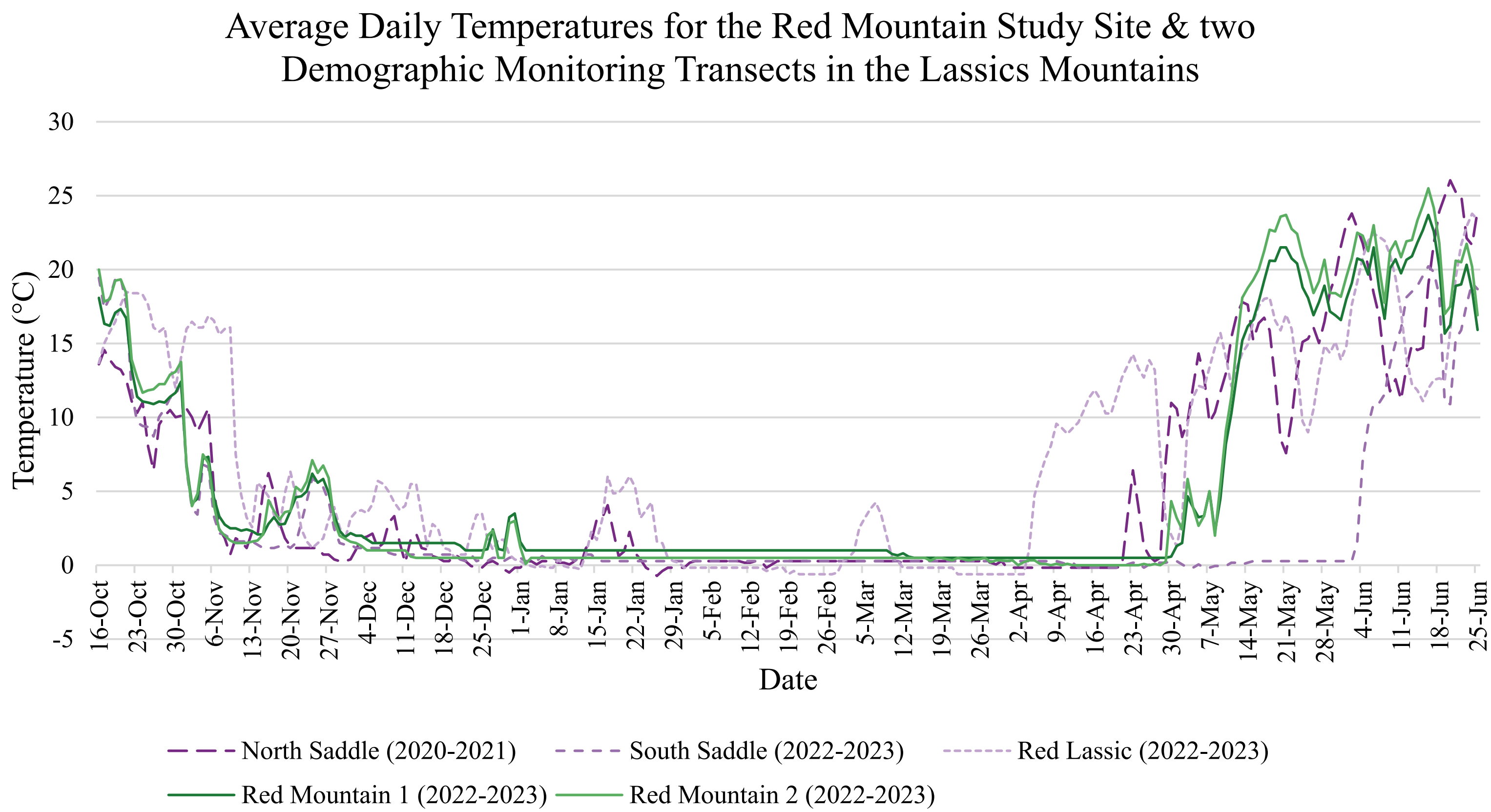


Figure 16. Line graph of the two iButton data loggers for the Red Mountain study site alongside the two most productive demographic monitoring transects (North & South Saddle and Red Lassic) during the same time interval between October 16, 2022 - June 25, 2023. Data obtained for the North Saddle were from October 16, 2020 - June 25, 2021, to supplement a lack of data collected during 2022 - 2023, and insufficient data collected during 2021 - 2022.

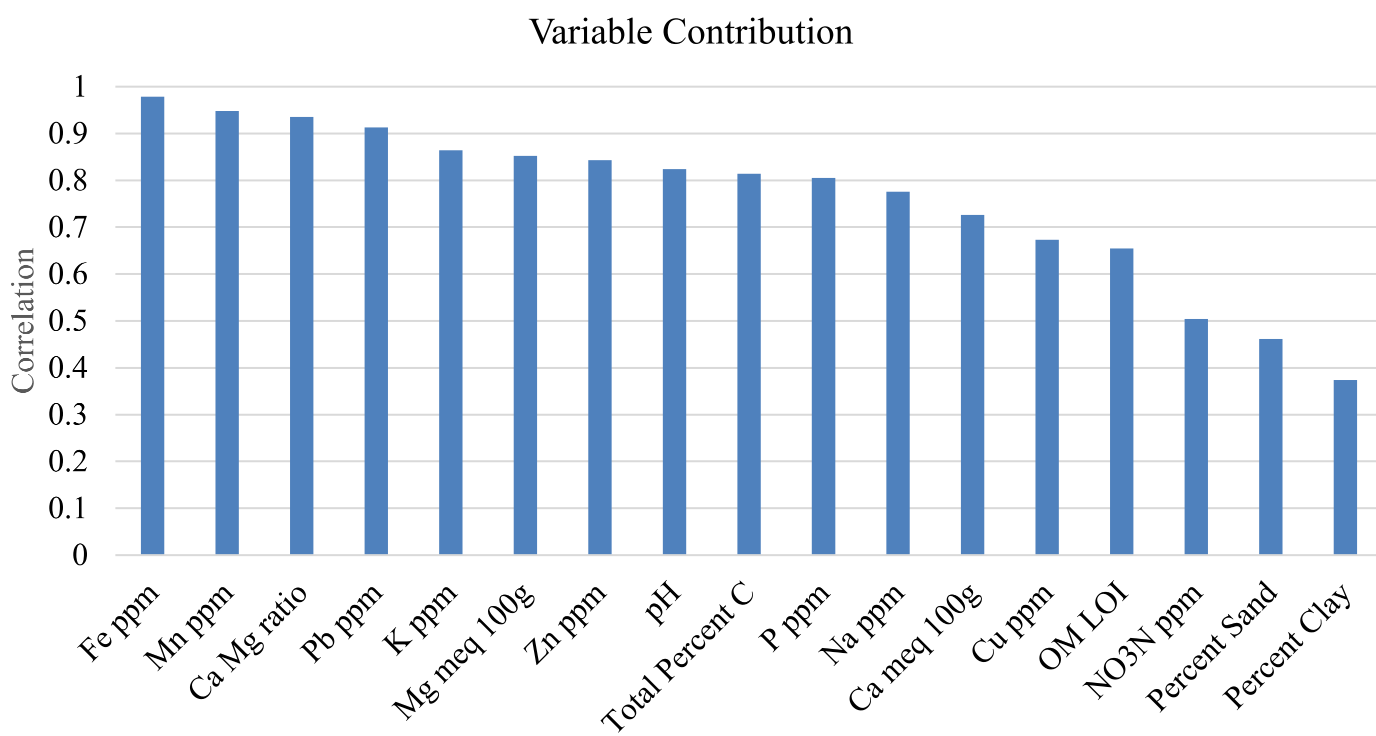


Figure 17. Bar graph showing the correlation values for each soil characteristic with respect to the first principal component, excluding percent silt and soil elements below 0.05 (minimum detection): Cd ppm, B ppm, Pb ppm, Cr ppm, Ni ppm, Mo ppm, and As ppm, as observed in Appendix D & E. The variables that contribute the most to principal component one in order of importance are iron (Fe ppm), manganese (Mn ppm), calcium - magnesium ratio (Ca - Mg ratio), lead (Pb ppm), potassium (K ppm), milliequivalents of magnesium (Mg meq 100g), zinc (Zn ppm), and pH.

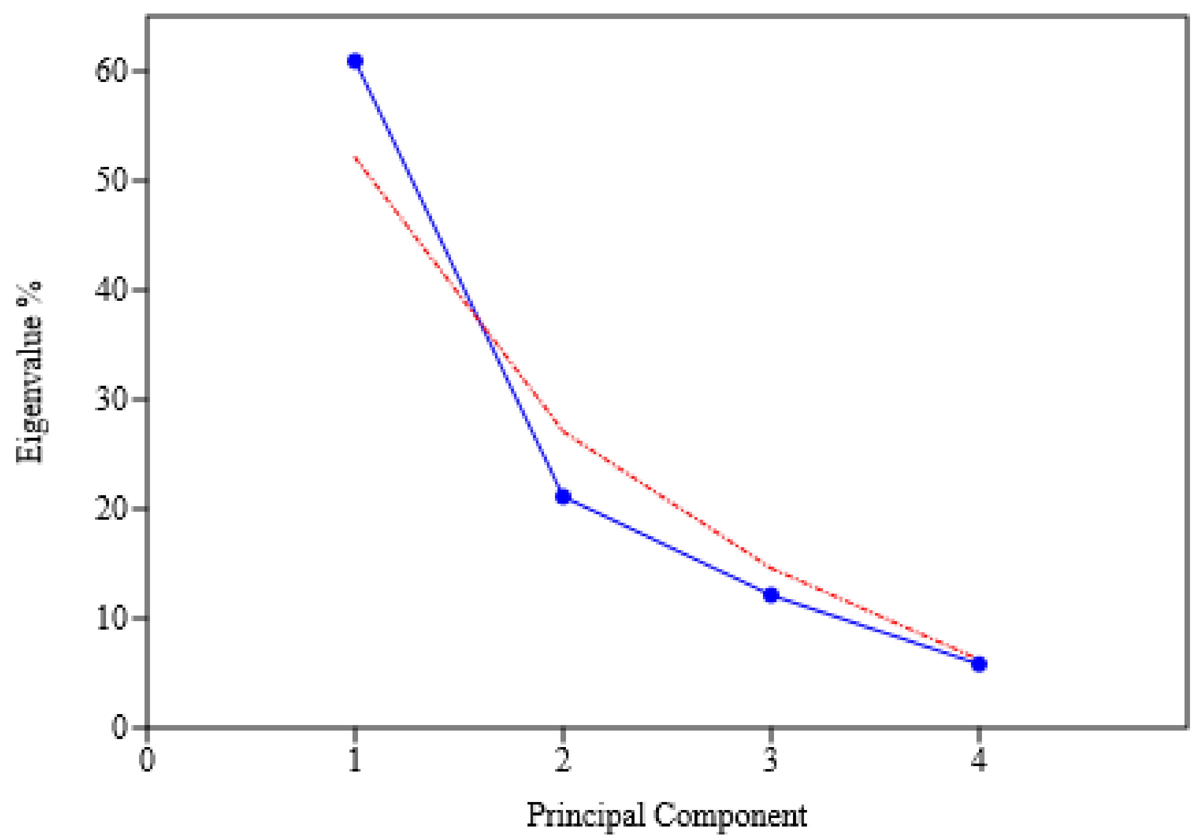


Figure 18. Scree plot produced from the correlation PCA biplot, visualizing the principal components and their importance for the soil characteristics observed in Figure 15 of all four study sites and the Lassics lupine soil samples (Appendix D & E). The first two principal components contain 82% of the total information of the data, making them the most significant. The y-axis represents the eigenvalues, or percentage of explained variances for each principal component; the x-axis represents each of the four principal components.

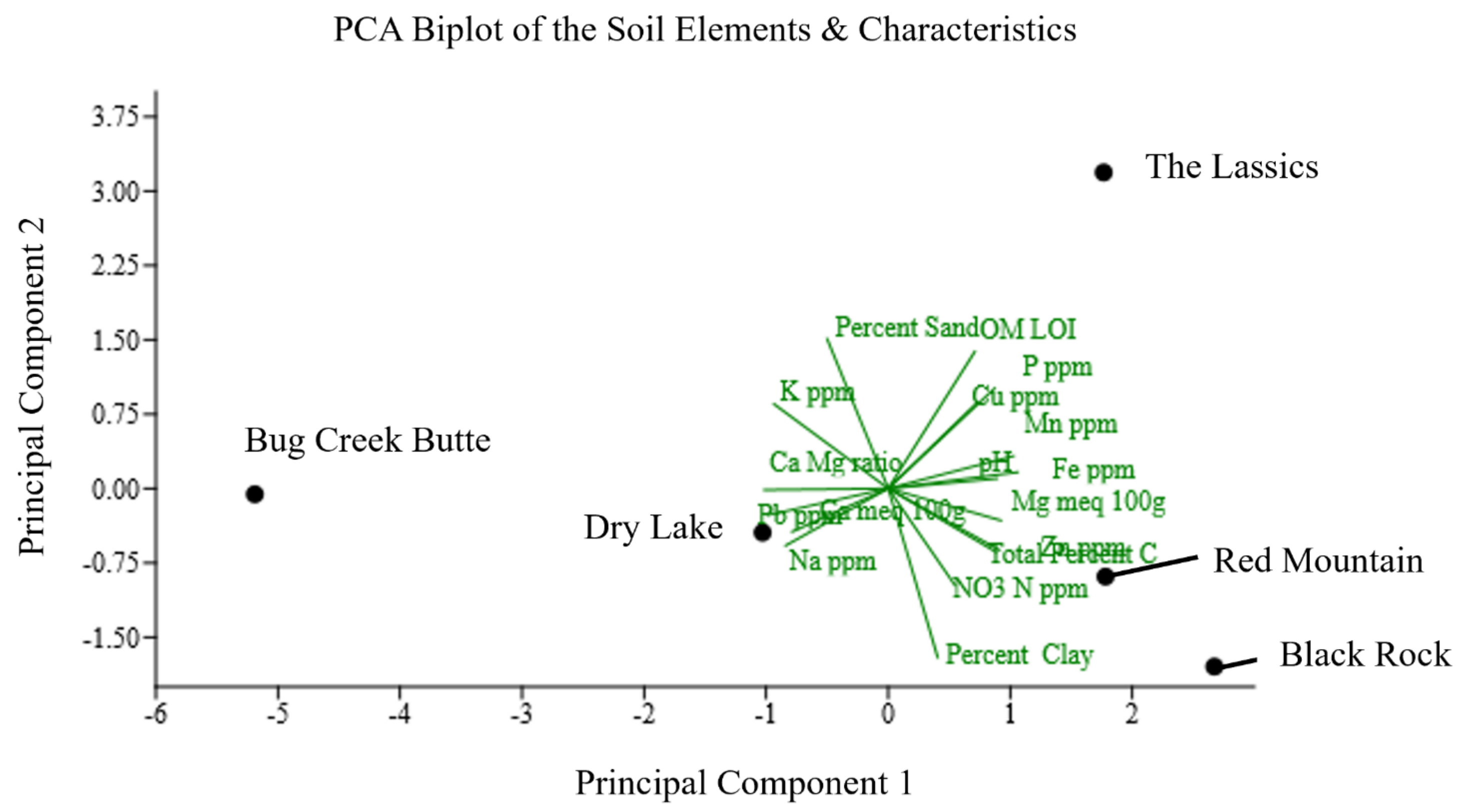


Figure 19. The correlative PCA biplot of the soil characteristic variables observed in Figure 15. Clustering of soil characteristics indicates high correlation amongst those variables. The length of the vectors of each soil characteristic represents the degree to which the variation is explained within that principal component. The Lassics, Red Mountain, and Black Rock are all more similar in soil characteristics when compared to Bug Creek Butte and Dry Lake.

Dendrogram Cluster Analysis of
Soil Elements & Characteristics

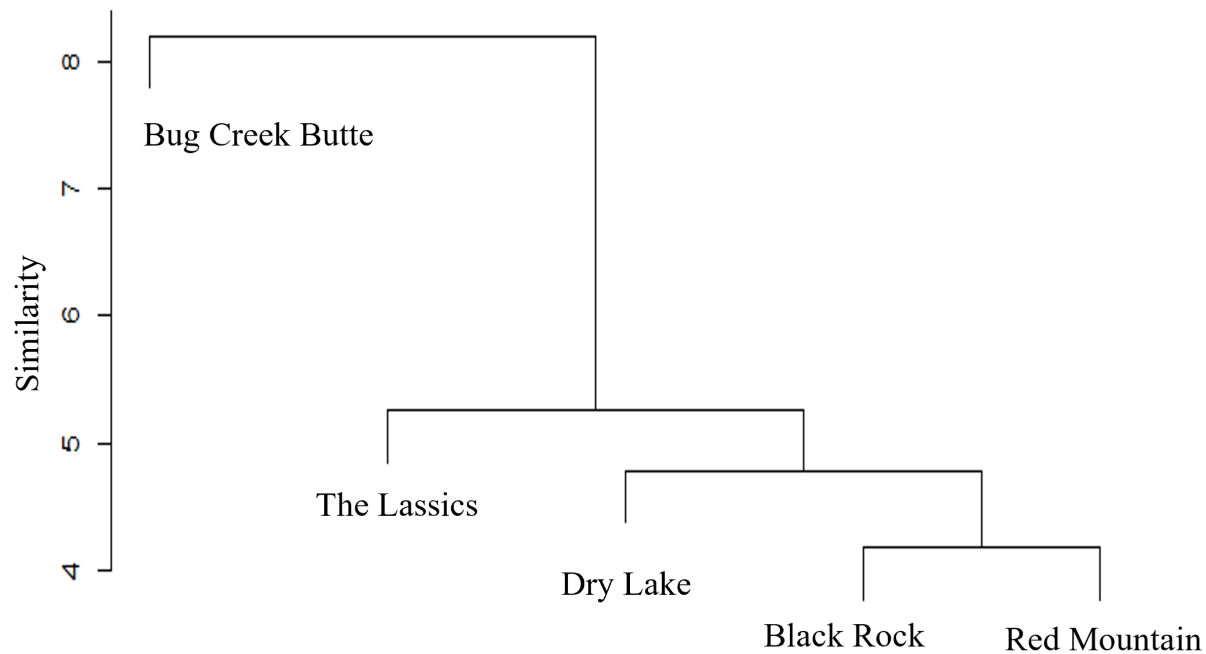


Figure 20. Dendrogram cluster analysis of the soil elements of all soil characteristics excluding percent silt and soil elements below 0.05 (minimum detection): Cd ppm, B ppm, Pb ppm, Cr ppm, Ni ppm, Mo ppm, and As ppm, as observed in Appendix D & E of the four study sites and the mean (Appendix D) of 10 occupied Lassics lupine habitat soil samples (Appendix E) based on Euclidean distance with one sample from each of the four study sites. Clustering of sites indicates closely related soil characteristics. Red Mountain and Black Rock are most similar in soil characteristics, followed by Dry Lake and the Lassics; the most dissimilar study site was Bug Creek Butte, since it was not a true serpentine barren.

APPENDICES

Appendix A. Soil analysis reports obtained from A & L Western Laboratories containing elemental content and textural composition from each of the four study sites.

A & L Western Laboratories, Inc.

1311 Woodland Avenue, Modesto CA 95351 209-529-4080
10220 SW Nimbus Avenue Bldg. K-9, Portland OR 97223 503-968-9225

SOIL ANALYSIS

Client: CAITLYN ALLCHIN
1855 SOUTH GWIN ROAD
McKINNLEYVILLE, CALIFORNIA 95519

Lab No.: 11-22S73507
Submitted Date: 11-22-23
Report Date: 11-29-23
Submitted By: CAITLYN ALLCHIN

Material: SOIL

PROJECT: CAL POLY - HUMBOLDT - STUDENT FORESTRY DEPARTMENT - 2023

	% SP	SP pH Paste	dS/m EC	meq/L Ca	meq/L Mg	meq/L Na	meq/L K	meq/L Cl	meq/L HCO_3	mg/L B	mg/L SO_4S	SAR	QUANT % $CaCO_3$ FREE LIME	NO_3N	PO_4P Olsen	K AA	Zn	Mn	Fe	Cu	% H_2O
			SPe Soil Solution Constituents											Extracted Nutrients mg/kg							
1. DL-001	56	5.9	0.17	0.0	1.4	<0.1	<0.1	<0.1		<0.1	3	0.0	<0.10	0.8	3.6	45	0.5	6.3	46.7	0.7	4.1
2. BCB-002	25	5.4	0.10	0.0	0.1	<0.1	<0.1	<0.1		<0.1	2	0.1	<0.10	0.8	2.7	51	0.2	0.8	21.4	0.6	1.6
3. RM-003	37	5.8	0.27	0.4	2.3	<0.1	<0.1	<0.1		<0.1	5	0.0	<0.10	4.4	6.0	34	0.7	7.6	63.0	1.3	2.7
4. BR-004	48	6.7	0.17	0.1	1.6	<0.1	<0.1	<0.1		<0.1	4	0.0	<0.10	2.4	6.2	31	1.3	11.6	58.8	0.8	4.6
OPTIMUM RANGES		6.0-7.5	<4.00 >0.60	Ca > 2x Mg & Na			>0.4	<10		>0.2 <1.5	>50 <400	<5	<2.0% <4.0%	<20.0	>25.0	>150	>2.0	>5.0	>8.0	>1.0	

	AMMONIUM ACETATE EXTRACTED CATIONS (ppm - %) Calcium mg/kg	Calcium %CEC	Magnesium mg/kg	Magnesium %CEC	Sodium mg/kg	Sodium %CEC	Potassium mg/kg	Potassium %CEC	C.E.C. meq/100g Sum	HEALTHY SOILS PROGRAM DATA % Organic Carbon	% Organic Matter	mg/kg TN	C : N Ratio	SPe Cation mg/L	SPe Soluble Cations Ca %SPe	Mg %SPe	Na %SPe	K %SPe
1. DL-001	618	38.2	575	59.2	22	1.2	45	1.4	8.1	1.44	2.48	879	16.4	21	4.6	83.3	1.1	10.8
2. BCB-002	912	77.4	134	19.0	19	1.4	51	2.2	5.9	0.38	0.65	553	6.8	4	5.6	26.4	7.1	60.9
3. RM-003	790	32.6	965	66.4	8	0.3	34	0.7	12.1	1.64	2.83	1110	14.8	38	21.3	73.0	0.6	5.2
4. BR-004	198	14.9	665	83.3	9	0.6	31	1.2	6.7	1.46	2.52	1060	13.8	24	6.9	81.5	2.5	9.0
DESIRED RANGES		>70%	100	10-20%	<150	<5.0%		>4.0%			1.0%				>60%		<20%	>7%

RED = LOW BLUE = HIGH DOMINANT SOLUBLE SALT IS UNDERLINED. SEE ENCLOSED INTERPRETATION GUIDES. mg/L = ppm mg/kg = ppm

	% SAND	% SILT	% CLAY	SOIL TEXTURE	Available Moisture inches per foot
1. DL-001	70.0	15.0	15.0	Sandy Loam	1.20 to 1.56
2. BCB-002	75.0	15.0	10.0	Sandy Loam	1.20 to 1.56
3. RM-003	65.0	17.5	17.5	Sandy Loam	1.20 to 1.56
4. BR-004	46.9	30.6	22.5	Loam	1.68 to 2.16

IF YOU SHOULD HAVE ANY QUESTIONS, PLEASE CALL. THANK YOU.

Patrick O'Brien - Certified Crop Adviser #366777
Joe O'Brien - Certified Crop Adviser #19120

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Account No. : 3411

Environmental Sample Analysis Report

A&L WESTERN AGRICULTURAL LABORATO
MODESTO & PORTLAND OFFICE
1311 WOODLAND AVE #1
MODESTO CA 95351

Invoice No. : 1147047
Date Received : 11/27/2023
Date Analyzed: 11/28/2023

Lab No. : 3947

Results For : S73507-04
Sample ID : BR 004

	Analysis Solid: Dry Wgt Liquid: As Rcvd	EPA Method Number	Lab. Tech.	Detection Limit
Arsenic As, mg/kg	0.52	3050B/6010C	L.D.S	0.01
Cadmium Cd, mg/kg	0.49	3050B/6010C	L.D.S	0.01
Chromium Cr, mg/kg	327.82	3050B/6010C	L.D.S	0.01
Copper Cu, mg/kg	18.18	3050B/6010C	L.D.S	0.01
Molybdenum Mo, mg/kg	0.86	3050B/6010C	L.D.S	0.01
Nickel Ni, mg/kg	2204.74	3050B/6010C	L.D.S	0.01
Lead Pb, mg/kg	2.02	3050B/6010C	L.D.S	0.01
Selenium Se, mg/kg	0.05	3050B/6010C	L.D.S	0.01
Zinc Zn, mg/kg	68.21	3050B/6010C	L.D.S	0.01
Mercury Hg, mg/kg	0.010	7473	L.D.S	0.01

Reviewed By : L.D. Severson - AgroLab/Matrix Sciences Inc 12/1/2023 Copy : 1

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Environmental Sample Analysis Report

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1311 WOODLAND AVE #1
MODESTO CA 95351

Invoice No. : 1147047
Date Received : 11/27/2023
Date Analyzed: 11/28/2023

Lab No. : 3945

Results For : S73507-02
Sample ID : BCB 002

	Analysis Solid: Dry Wgt Liquid: As Rcvd	EPA Method Number	Lab. Tech.	Detection Limit
Arsenic As, mg/kg	4.85	3050B/6010C	L.D.S	0.01
Cadmium Cd, mg/kg	0.29	3050B/6010C	L.D.S	0.01
Chromium Cr, mg/kg	44.83	3050B/6010C	L.D.S	0.01
Copper Cu, mg/kg	19.78	3050B/6010C	L.D.S	0.01
Molybdenum Mo, mg/kg	0.56	3050B/6010C	L.D.S	0.01
Nickel Ni, mg/kg	40.47	3050B/6010C	L.D.S	0.01
Lead Pb, mg/kg	11.15	3050B/6010C	L.D.S	0.01
Selenium Se, mg/kg	0.05	3050B/6010C	L.D.S	0.01
Zinc Zn, mg/kg	55.40	3050B/6010C	L.D.S	0.01
Mercury Hg, mg/kg	0.006	7473	L.D.S	0.01

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Invoice No. : 1147047
Date Received : 11/27/2023
Date Analyzed: 11/28/2023

Lab No. : 3944

Results For : S73507-01
Sample ID : DL 001

	Analysis Solid: Dry Wgt Liquid: As Rcvd	EPA Method Number	Lab. Tech.	Detection Limit
Arsenic As, mg/kg	0.64	3050B/6010C	L.D.S	0.01
Cadmium Cd, mg/kg	0.64	3050B/6010C	L.D.S	0.01
Chromium Cr, mg/kg	1110.59	3050B/6010C	L.D.S	0.01
Copper Cu, mg/kg	18.83	3050B/6010C	L.D.S	0.01
Molybdenum Mo, mg/kg	1.58	3050B/6010C	L.D.S	0.01
Nickel Ni, mg/kg	1528.30	3050B/6010C	L.D.S	0.01
Lead Pb, mg/kg	2.02	3050B/6010C	L.D.S	0.01
Selenium Se, mg/kg	0.06	3050B/6010C	L.D.S	0.01
Zinc Zn, mg/kg	35.60	3050B/6010C	L.D.S	0.01
Mercury Hg, mg/kg	0.009	7473	L.D.S	0.01

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Invoice No. : 1147047
Date Received : 11/27/2023
Date Analyzed: 11/28/2023

Lab No. : 3946

Results For : S73507-03
Sample ID : RM 003

	Analysis Solid: Dry Wgt Liquid: As Rcvd	EPA Method Number	Lab. Tech.	Detection Limit
Arsenic As, mg/kg	0.62	3050B/6010C	L.D.S	0.01
Cadmium Cd, mg/kg	0.44	3050B/6010C	L.D.S	0.01
Chromium Cr, mg/kg	697.16	3050B/6010C	L.D.S	0.01
Copper Cu, mg/kg	28.45	3050B/6010C	L.D.S	0.01
Molybdenum Mo, mg/kg	0.68	3050B/6010C	L.D.S	0.01
Nickel Ni, mg/kg	913.85	3050B/6010C	L.D.S	0.01
Lead Pb, mg/kg	0.51	3050B/6010C	L.D.S	0.01
Selenium Se, mg/kg	0.06	3050B/6010C	L.D.S	0.01
Zinc Zn, mg/kg	62.57	3050B/6010C	L.D.S	0.01
Mercury Hg, mg/kg	0.005	7473	L.D.S	0.01

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Appendix B. Plant species observed within each of the four study sites as well as the surrounding habitat. Abbreviations: UM = ultramafic affinity on a scale from 1 - 6 from weak indicator to strict endemic, respectively; CRPR = CA rare plant rank from 1 - 4 from rarest to limited distribution, respectively; BR = Black Rock; BCB = Bug Creek Butte; DL = Dry Lake; RM = Red Mountain. Asterisk = species present within the study site used for the Shannon-Weiner diversity indices and Jaccard similarity index.

Scientific Name	Common Name	UM	CRPR	Family	BR	BCB	DL	RM
Abies concolor	White silver fir			Pinaceae	X	X		
Achillea millefolium	Yarrow			Asteraceae	X*			X*
Allium campanulatum	Dusky onion			Alliaceae				X*
Allium falcifolium	Sickle leaf onion	4.2		Alliaceae	X*	X*	X*	
Amelanchier alnifolia	Service berry			Rosaceae	X			
Anisocarpus scabridus	Scabrid alpine tarplant		1B.3	Asteraceae		X*		
Aphyllon purpureum	Naked broom rape			Orobanchaceae		X*		
Arbutus menziesii	Madrono			Ericaceae			X	
Arctostaphylos manzanita ssp. manzanita	Common manzanita			Ericaceae	X			
Arctostaphylos nevadensis	Pine mat manzanita			Ericaceae	X			
Arctostaphylos patula	Green leaf manzanita			Ericaceae	X			
Arnica cordifolia	Heart leaved arnica			Asteraceae		X		
Arnica discoidea	Rayless arnica			Asteraceae			X	
Aspidotis densa	Lace fern	3.4		Pteridaceae			X	X
Astragalus purshii var. lectulus	Pursh's milk vetch			Fabaceae		X*		
Boechera pinetorum	Woodland rockcress			Brassicaceae				X
Boechera serpenticola	Serpentine rockcress	5.3	1B.2	Brassicaceae				X*
Calocedrus decurrens	Incense cedar	3		Cupressaceae	X*	X*	X*	
Calochortus tolmiei	Hairy star tulip			Liliaceae	X*	X*		
Calystegia occidentalis	Bush morning glory			Convolvulaceae				X
Cardamine californica	Bitter cress			Brassicaceae	X			
Ceanothus cordulatus	Mountain whitethorn			Rhamnaceae		X	X	
Ceanothus cuneatus var. cuneatus	Buck brush	1.5		Rhamnaceae				X
Ceanothus integerrimus	Deer brush			Rhamnaceae				X

Scientific Name	Common Name	UM	CRPR	Family	BR	BCB	DL	RM
Ceanothus prostratus	Mahala mats			Rhamnaceae				X
Chorizanthe membranacea	Pink spineflower			Polygonaceae				X*
Cirsium cymosum car. Cymosum	Peregrine thistle	3		Asteraceae				X*
Claytonia saxosa	Brandegee's spring beauty	4.4		Montiaceae		X*		
Collinsia linearis	Narrow leaf collinsia			Plantaginaceae				X
Collomia tracyi	Tracy's collomia		4.3	Polemoniaceae			X*	X*
Corallorhiza striata	Striped coral root			Orchidaceae		X		
Crepis pleurocarpa	Naked stemmed hawksbeard	2		Asteraceae		X*	X*	X*
Dichelostemma congestum	Fork toothed ookow			Themidaceae				X
Diplacus nanus	Dwarf monkey flower			Phrymaceae				X*
Elymus elymoides	Squirrel tail grass			Poaceae			X	X
Elymus glaucus	Blue wildrye			Poaceae	X			
Epilobium septentrionale	Humboldt county fuchsia			Onagraceae		X		
Ericameria nauseosa	Rubber rabbitbrush			Asteraceae		X		
Erigeron maniopotamicus	Mad river fleabane daisy		1B.2	Asteraceae		X		
Eriogonum compositum var. compositum	Arrow leaf buckwheat			Polygonaceae		X		
Eriogonum luteolum var. luteolum	Golden buckwheat			Polygonaceae				X
Eriogonum nudum	Naked buckwheat			Polygonaceae	X			X
Eriogonum umbellatum	Sulfur buckwheat			Polygonaceae		X		X
Eriophyllum lanatum var. achilleoides	Yarrow leaved woolly sunflower	2.3		Asteraceae	X*	X*		X*
Erysimum capitatum	Wallflower			Brassicaceae		X	X	
Erythronium californicum	California fawn lily			Liliaceae	X*		X*	
Fritillaria glauca	Siskiyou missionbells		4.2	Liliaceae		X		X
Fritillaria purdyi	Purdy's fritillary	4.5	4.3	Liliaceae	X*	X*		
Fritillaria recurva	Scarlet fritillary	2.7		Liliaceae				X

Scientific Name	Common Name	UM	CRPR	Family	BR	BCB	DL	RM
Galium ambiguum ssp. siskiyouense	Siskiyou bedstraw	5.5		Rubiaceae				X
Galium aparine	Cleavers			Rubiaceae		X		X
Garrya fremontii	Fremont's silk tassel			Garryaceae	X			
Gilia capitata ssp. capitata	Blue field gilia	1.6		Polemoniaceae				X
Gilia capitata ssp. pacifica	Pacific blue field gilia		1B.2	Polemoniaceae		X		
Hieracium albiflorum	White flowered hawkweed			Asteraceae	X*		X*	
Holodiscus discolor	Oceanspray	1		Rosaceae		X		X
Horkelia tridentata var. flavescens	Three toothed horkelia	3		Rosaceae		X*		
Hosackia crassifolia	Broad leaved lotus			Fabaceae			X	
Ipomopsis aggregata	Scarlet gilia			Polemoniaceae				X
Iris purdyi	Purdy's iris			Iridaceae	X	X		
Lactuca serriola	Prickly lettuce			Asteraceae			X	X
Lathyrus polyphyllus	Oregon pea			Fabaceae		X		
Leptosiphon bicolor	True babystars			Polemoniaceae		X		
Lewisia triphylla	Three leaved lewisia	1.7		Montiaceae		X		
Lilium rubescens	Chaparral lily	2	4.2	Liliaceae			X	
Lithophragma campanulatum	Siskiyou mountain woodland star			Saxifragaceae		X		
Lomatium californicum	Celery weed			Apiaceae	X*	X*		X*
Lomatium macrocarpum	Large fruited lomatium	2.7		Apiaceae	X*	X*	X*	X*
Lupinus latifolius var. latifolius	Broad leaf lupine			Fabaceae	X*			
Lupinus lepidus var. lobbii	Lobb's lupine			Fabaceae			X	
Lysimachia latifolia	Pacific starflower			Myrsinaceae	X			
Maianthemum racemosum	Feathery false lily of the valley			Ruscaceae	X			
Mentzelia dispersa	Scattered blazing star			Loasaceae				X
Microsteris gracilis	Slender phlox			Polemoniaceae				X
Minuartia nuttallii var. gregaria	Nuttall sandwort			Caryophyllaceae			X	

Scientific Name	Common Name	UM	CRPR	Family	BR	BCB	DL	RM
Moehringia macrophylla	Large leaved sandwort	2.7		Caryophyllaceae	X	X	X	
Monardella purpurea	Siskiyou monardella	6		Lamiaceae		X		X
Osmorhiza occidentalis	Western sweet cicely			Apiaceae	X			
Paxistima myrsinites	Oregon boxwood			Celastraceae	X			
Penstemon anguineus	Siskiyou beardtongue			Plantaginaceae			X	
Penstemon purpusii	Snow mtn. beardtongue	2.8		Plantaginaceae	X*	X*	X*	X*
Phacelia corymbosa	Serpentine phacelia	5.5		Boraginaceae				X
Phlox diffusa	Spreading phlox			Polemoniaceae	X*	X*		X*
Phoenicaulis cheiranthoides	Dagger pod			Brassicaceae		X*		
Pinus jeffreyi	Jeffrey pine	2.7		Pinaceae	X*		X*	X*
Plagiobothrys tenellus	Slender popcorn flower			Boraginaceae				X
Polystichum imbricans	Narrow leaved sword fern			Dryopteridaceae		X		
Pseudotsuga menziesii	Douglas fir			Pinaceae	X	X		X
Pyrola picta	White veined wintergreen			Ericaceae			X	
Quercus chrysolepis	Gold cup live oak			Fagaceae				X
Quercus garryana	Oregon oak			Fagaceae	X	X		
Quercus garryana var. breweri	Oregon oak			Fagaceae		X		X
Quercus kelloggii	California black oak			Fagaceae				X
Quercus vacciniifolia	Huckleberry oak	2.5		Fagaceae	X			
Ranunculus occidentalis	Western buttercup			Ranunculaceae	X			
Ribes lobbii	Gummy gooseberry			Grossulariaceae			X	
Ribes roezlii var. roezlii	Sierra gooseberry			Grossulariaceae		X		
Rosa gymnocarpa	Wood rose			Rosaceae	X			
Sabulina rosei	Peanut sandwort		4.2	Caryophyllaceae				X
Scutellaria antirrhinoides	Snapdragon skullcap	2.3		Lamiaceae				X*
Sedum flavidum	pale yellow stonecrop	6	4.3	Crassulaceae		X*		X*

Scientific Name	Common Name	UM	CRPR	Family	BR	BCB	DL	RM
Silene greenei ssp. greenei	bell catchfly			Caryophyllaceae	X			
Silene laciniata	Cardinal catchfly			Caryophyllaceae				X
Streptanthus tortuosus	Jewelweed			Brassicaceae		X*		X*
Symphoricarpos mollis	Snowberry			Caprifoliaceae	X			
Toxicoscordion micranthum	Small flowered star lily			Melanthiaceae		X		
Trillium ovatum	Western wakerobin			Melanthiaceae	X			
Viola sheltonii	Shelton's violet			Violaceae		X		
Wyethia angustifolia	Narrow leaved mule ears			Asteraceae				X
Wyethia longicaulis	Humboldt county wyethia		4.3	Asteraceae		X		

Appendix C. Soil temperature data from the four study sites alongside the Lassics lupine North and South Saddle and Red Lassic demographic monitoring transects during the same time period of October 16, 2022 to June 25, 2023; data from the North Saddle were obtained from a prior season (2020 - 2021) due to a lack of data for the 2022 - 2023 season. Temperature values are in degrees Celsius.

Date	North Saddle	South Saddle	Red Lassic	Black Rock 1	Black Rock 2	Bug Creek Butte 1	Bug Creek Butte 2	Dry Lake 1	Dry Lake 2	Red Mountain 1	Red Mountain 2
10/16/2022	13.60	19.44	13.68	20.92	18.67	16.50	16.92	13.83	13.25	18.08	20.00
10/17/2022	14.56	17.33	15.01	19.50	17.40	15.50	15.50	13.10	12.60	16.33	17.83
10/18/2022	13.89	18.11	15.79	18.92	16.92	15.25	15.50	13.33	12.58	16.20	18.00
10/19/2022	13.42	19.36	16.47	20.33	17.92	16.00	16.33	14.25	13.50	17.08	19.25
10/20/2022	13.22	19.46	17.63	21.40	18.70	16.60	16.90	14.80	13.80	17.33	19.33
10/21/2022	12.56	17.63	18.49	19.25	17.50	15.08	15.50	13.92	13.50	16.70	18.40
10/22/2022	11.10	11.76	18.40	12.92	11.90	8.10	8.30	9.08	9.08	13.25	13.92
10/23/2022	10.31	9.67	18.40	11.60	9.75	5.83	6.42	5.80	6.10	11.40	12.70
10/24/2022	11.00	9.42	18.31	10.33	9.00	7.00	7.33	7.08	7.25	11.08	11.67
10/25/2022	8.04	9.36	17.63	10.10	9.00	7.00	7.40	5.90	6.70	11.00	11.83
10/26/2022	6.40	8.71	16.08	9.92	8.67	5.50	5.67	4.92	5.42	10.90	11.90
10/27/2022	9.51	10.03	15.79	9.83	8.67	5.83	6.25	5.33	5.58	11.08	12.25
10/28/2022	10.11	10.57	16.08	10.70	9.70	7.40	7.50	6.00	6.20	11.00	12.25
10/29/2022	10.50	11.33	13.50	11.08	10.08	7.58	7.83	6.33	6.33	11.40	12.90
10/30/2022	10.01	11.43	12.01	11.92	10.42	7.50	7.75	6.42	6.08	11.67	13.08
10/31/2022	10.11	12.53	14.06	13.00	10.70	8.00	8.30	7.60	6.90	12.42	13.75
11/1/2022	10.60	6.50	15.99	7.58	6.50	4.42	4.75	4.58	4.83	6.80	6.60
11/2/2022	10.01	3.85	16.47	5.67	4.33	2.50	2.83	2.67	3.83	4.17	4.00
11/3/2022	9.03	3.43	16.08	4.70	3.90	2.00	2.60	2.40	3.50	4.50	4.83
11/4/2022	9.82	6.81	16.08	6.08	3.67	3.50	5.50	3.75	4.17	7.20	7.50
11/5/2022	10.61	6.63	16.86	7.00	5.92	6.00	6.42	6.17	6.25	7.33	6.92
11/6/2022	5.15	3.32	16.56	3.60	2.80	1.90	2.40	3.20	3.50	4.58	4.08
11/7/2022	2.44	2.15	15.61	3.50	2.67	1.00	2.00	2.08	3.00	3.30	2.40

Date	North Saddle	South Saddle	Red Lassic	Black Rock 1	Black Rock 2	Bug Creek Butte 1	Bug Creek Butte 2	Dry Lake 1	Dry Lake 2	Red Mountain 1	Red Mountain 2
11/8/2022	1.83	2.06	15.99	3.50	2.50	1.00	1.67	1.83	2.75	2.75	2.00
11/9/2022	0.72	1.83	16.08	3.50	2.50	1.00	1.50	1.50	2.50	2.50	1.67
11/10/2022	1.82	1.61	7.50	3.08	2.50	1.00	1.50	1.50	2.50	2.50	1.50
11/11/2022	1.60	1.61	4.76	2.92	2.00	1.00	1.50	1.50	2.50	2.33	1.50
11/12/2022	1.17	1.61	3.22	2.50	2.00	1.00	1.50	1.50	2.40	2.42	1.50
11/13/2022	2.25	1.61	2.57	2.83	2.00	1.00	1.50	1.50	2.00	2.30	1.60
11/14/2022	2.04	1.39	5.58	2.83	2.00	1.00	1.50	1.50	2.17	2.08	1.67
11/15/2022	4.97	1.17	5.17	2.70	1.90	1.00	1.50	1.50	2.00	2.08	2.08
11/16/2022	6.22	1.17	4.65	3.00	1.50	1.00	1.50	1.17	2.00	2.80	4.40
11/17/2022	4.89	1.17	3.42	4.50	1.50	1.00	1.42	1.00	2.00	3.25	3.67
11/18/2022	2.89	1.28	2.58	4.90	1.50	1.00	1.50	1.00	2.00	2.75	3.08
11/19/2022	1.83	1.39	4.89	4.75	1.42	1.00	1.33	1.08	2.00	2.80	3.60
11/20/2022	1.28	1.17	6.32	5.75	2.90	1.00	1.50	1.00	2.00	3.67	3.67
11/21/2022	1.17	1.50	4.78	6.40	3.33	1.00	1.00	1.00	2.00	4.60	5.30
11/22/2022	1.17	2.88	2.46	6.33	4.25	0.83	1.00	1.00	1.75	4.67	5.00
11/23/2022	1.17	4.33	1.61	7.00	5.00	0.50	1.00	1.00	1.60	5.00	5.67
11/24/2022	1.17	5.88	1.17	8.00	6.00	0.50	1.00	2.25	2.50	6.20	7.10
11/25/2022	1.17	5.60	1.49	7.58	5.75	0.50	1.17	2.42	2.83	5.58	6.25
11/26/2022	0.72	5.28	1.82	7.90	6.30	0.50	2.00	2.70	3.10	5.83	6.75
11/27/2022	0.72	4.33	3.08	7.17	5.50	0.50	1.75	1.58	2.17	4.90	5.90
11/28/2022	0.39	2.47	3.93	4.08	3.42	0.50	1.08	1.25	1.67	3.42	3.00
11/29/2022	0.28	1.50	2.57	3.60	2.10	0.50	0.50	1.00	1.00	2.33	2.00
11/30/2022	0.28	1.39	1.71	2.50	1.50	0.50	0.50	1.00	1.00	1.90	1.80
12/1/2022	0.39	1.39	3.18	2.50	1.75	0.50	0.50	1.00	1.00	2.17	1.58
12/2/2022	1.06	1.17	3.61	2.50	1.50	0.50	0.50	1.00	1.00	2.00	1.50
12/3/2022	1.82	1.17	3.72	2.50	1.50	0.50	0.67	1.00	1.42	2.00	1.30
12/4/2022	1.93	1.17	3.53	2.25	1.50	0.50	1.00	1.00	1.50	1.75	1.00
12/5/2022	2.14	1.17	4.13	2.00	1.50	0.50	1.00	1.00	1.50	1.50	1.00
12/6/2022	1.17	1.17	5.69	2.00	1.50	0.50	1.00	1.00	1.50	1.50	1.00

Date	North Saddle	South Saddle	Red Lassic	Black Rock 1	Black Rock 2	Bug Creek Butte 1	Bug Creek Butte 2	Dry Lake 1	Dry Lake 2	Red Mountain 1	Red Mountain 2
12/7/2022	1.49	1.17	5.50	2.00	1.50	0.50	1.00	1.00	1.50	1.50	1.00
12/8/2022	2.89	0.83	4.97	2.00	1.50	0.50	1.00	1.00	1.50	1.50	1.00
12/9/2022	3.32	0.72	4.25	2.00	1.50	0.50	1.00	1.00	1.33	1.50	1.00
12/10/2022	1.50	0.72	3.74	2.00	1.20	0.50	0.90	1.00	1.00	1.50	1.00
12/11/2022	0.17	0.72	4.03	2.00	1.00	0.50	0.75	0.83	1.00	1.50	1.00
12/12/2022	1.71	0.72	5.49	2.00	1.00	0.50	0.58	0.58	1.00	1.50	0.58
12/13/2022	2.14	0.72	5.50	1.90	1.00	0.50	0.50	0.50	1.00	1.50	0.50
12/14/2022	1.17	0.72	3.40	1.67	1.00	0.50	0.50	0.50	1.00	1.50	0.50
12/15/2022	1.06	0.72	1.28	1.50	1.00	0.50	0.50	0.50	1.00	1.50	0.50
12/16/2022	0.61	0.72	2.78	1.50	1.00	0.50	0.50	0.50	1.00	1.50	0.50
12/17/2022	0.50	0.72	2.47	1.50	1.00	0.50	0.50	0.50	1.00	1.50	0.50
12/18/2022	0.28	0.72	1.17	1.50	1.00	0.50	0.50	0.50	1.00	1.50	0.50
12/19/2022	0.28	0.72	1.06	1.50	1.00	0.50	0.50	0.50	1.00	1.50	0.50
12/20/2022	0.72	0.72	0.50	1.50	1.00	0.50	0.50	0.50	1.00	1.50	0.50
12/21/2022	0.50	0.39	0.72	1.50	1.00	0.50	0.50	0.50	0.92	1.33	0.50
12/22/2022	0.28	0.28	0.72	1.50	1.00	0.50	0.50	0.50	0.80	1.00	0.50
12/23/2022	-0.06	0.72	2.22	1.50	1.08	0.00	0.50	0.50	0.33	1.00	0.50
12/24/2022	-0.17	0.28	3.39	1.50	1.50	0.20	0.50	0.50	0.50	1.00	0.50
12/25/2022	-0.17	0.39	3.51	1.50	4.58	0.00	0.50	0.50	0.50	1.00	0.50
12/26/2022	0.17	0.28	1.82	1.58	5.50	0.00	0.50	0.50	0.50	1.08	2.00
12/27/2022	0.28	0.50	1.06	2.60	2.80	0.00	0.50	0.30	0.50	2.42	2.33
12/28/2022	0.06	0.50	1.71	1.50	2.75	0.00	0.50	0.50	0.75	1.10	0.50
12/29/2022	-0.28	0.28	1.72	1.25	1.75	0.00	0.50	0.50	0.83	1.00	0.50
12/30/2022	-0.50	0.50	0.72	2.90	5.20	0.00	0.50	0.30	1.00	3.25	2.83
12/31/2022	-0.17	0.61	0.39	3.75	5.83	0.00	0.50	0.50	1.42	3.50	3.00
1/1/2023	-0.17	0.50	0.28	2.83	3.83	0.00	0.50	0.50	0.58	1.58	1.25
1/2/2023	0.17	0.28	0.06	1.50	1.90	0.00	0.50	0.50	0.50	1.00	0.08
1/3/2023	0.28	0.28	-0.06	1.50	1.58	0.00	0.50	0.50	0.50	1.00	0.50
1/4/2023	0.06	0.28	-0.17	1.50	1.50	0.00	0.50	0.50	0.50	1.00	0.50

Date	North Saddle	South Saddle	Red Lassic	Black Rock 1	Black Rock 2	Bug Creek Butte 1	Bug Creek Butte 2	Dry Lake 1	Dry Lake 2	Red Mountain 1	Red Mountain 2
1/5/2023	0.28	0.61	-0.06	1.50	1.40	0.00	0.50	0.50	0.40	1.00	0.50
1/6/2023	0.28	0.39	-0.17	1.50	1.00	0.00	0.50	0.50	0.50	1.00	0.50
1/7/2023	0.28	0.50	-0.17	1.50	1.00	0.00	0.50	0.50	0.50	1.00	0.50
1/8/2023	0.17	0.28	0.39	1.20	1.00	0.00	0.50	0.50	0.50	1.00	0.50
1/9/2023	0.17	0.50	-0.06	1.00	1.00	0.00	0.50	0.50	0.50	1.00	0.50
1/10/2023	0.06	0.50	-0.17	1.00	1.00	0.00	0.50	0.50	0.50	1.00	0.50
1/11/2023	0.28	0.28	-0.17	1.00	0.83	0.00	0.50	0.40	0.40	1.00	0.50
1/12/2023	-0.06	0.61	-0.28	1.00	0.50	0.00	0.50	0.33	0.50	1.00	0.50
1/13/2023	1.14	0.72	0.71	1.00	0.80	0.00	0.50	0.30	0.20	1.00	0.50
1/14/2023	1.60	0.72	2.25	1.00	2.08	0.00	0.50	0.50	0.50	1.00	0.50
1/15/2023	3.10	0.39	1.71	1.00	1.33	0.00	0.50	0.50	0.50	1.00	0.50
1/16/2023	3.21	0.28	3.10	1.00	1.00	0.00	0.50	0.50	0.50	1.00	0.50
1/17/2023	4.06	0.28	6.01	1.00	0.75	0.00	0.50	0.50	0.50	1.00	0.50
1/18/2023	2.36	0.28	4.86	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
1/19/2023	0.61	0.28	4.89	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
1/20/2023	0.93	0.28	5.38	1.00	0.50	0.00	0.50	0.50	0.92	1.00	0.50
1/21/2023	2.25	0.28	6.01	1.00	0.50	0.00	0.50	0.50	1.00	1.00	0.50
1/22/2023	0.83	0.28	5.29	1.00	0.50	0.00	0.50	0.50	1.00	1.00	0.50
1/23/2023	0.39	0.28	3.21	1.00	0.50	0.00	0.50	0.50	0.92	1.00	0.50
1/24/2023	-0.17	0.28	3.71	1.00	0.50	0.00	0.50	0.50	0.67	1.00	0.50
1/25/2023	-0.39	0.28	4.25	1.00	0.50	0.00	0.50	0.50	0.60	1.00	0.50
1/26/2023	-0.72	0.28	1.61	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
1/27/2023	-0.39	0.28	1.49	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
1/28/2023	-0.17	0.28	0.50	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
1/29/2023	-0.17	0.28	0.28	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
1/30/2023	-0.17	0.28	0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
1/31/2023	-0.17	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/1/2023	0.17	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/2/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50

Date	North Saddle	South Saddle	Red Lassic	Black Rock 1	Black Rock 2	Bug Creek Butte 1	Bug Creek Butte 2	Dry Lake 1	Dry Lake 2	Red Mountain 1	Red Mountain 2
2/3/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/4/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/5/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/6/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/7/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/8/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/9/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/10/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/11/2023	0.17	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/12/2023	0.17	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/13/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/14/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/15/2023	-0.17	0.28	-0.39	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/16/2023	0.06	0.28	-0.28	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/17/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/18/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/19/2023	0.28	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/20/2023	0.28	0.28	-0.39	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/21/2023	0.28	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/22/2023	0.28	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/23/2023	0.28	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/24/2023	0.28	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/25/2023	0.28	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/26/2023	0.28	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/27/2023	0.28	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
2/28/2023	0.28	0.28	-0.50	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
3/1/2023	0.28	0.28	0.26	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
3/2/2023	0.28	0.28	0.50	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
3/3/2023	0.28	0.28	0.92	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50

Date	North Saddle	South Saddle	Red Lassic	Black Rock 1	Black Rock 2	Bug Creek Butte 1	Bug Creek Butte 2	Dry Lake 1	Dry Lake 2	Red Mountain 1	Red Mountain 2
3/4/2023	0.28	0.28	2.54	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
3/5/2023	0.28	0.28	3.19	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
3/6/2023	0.28	0.28	3.81	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
3/7/2023	0.28	0.28	4.24	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
3/8/2023	0.28	0.28	3.40	1.00	0.50	0.00	0.50	0.50	0.50	1.00	0.50
3/9/2023	0.28	0.28	1.93	1.00	0.50	0.00	0.50	0.50	0.42	1.00	0.50
3/10/2023	0.28	0.28	0.50	1.00	0.50	0.00	0.50	0.50	0.50	0.75	0.50
3/11/2023	0.28	0.28	0.28	1.00	0.50	0.00	0.50	0.50	0.50	0.67	0.50
3/12/2023	0.28	0.17	-0.17	1.00	0.50	0.00	0.50	0.50	0.42	0.80	0.50
3/13/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.00	0.58	0.50
3/14/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.00	0.50	0.50
3/15/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.42	0.50	0.50
3/16/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.50
3/17/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.30
3/18/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.50
3/19/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.50
3/20/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.40
3/21/2023	0.28	0.28	-0.17	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.33
3/22/2023	0.28	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.50
3/23/2023	0.28	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.40
3/24/2023	0.28	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.33
3/25/2023	0.28	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.40
3/26/2023	0.28	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.42
3/27/2023	0.28	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.50
3/28/2023	0.17	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.20
3/29/2023	0.06	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.33
3/30/2023	0.28	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.33
3/31/2023	-0.17	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.30
4/1/2023	-0.17	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.33

Date	North Saddle	South Saddle	Red Lassic	Black Rock 1	Black Rock 2	Bug Creek Butte 1	Bug Creek Butte 2	Dry Lake 1	Dry Lake 2	Red Mountain 1	Red Mountain 2
4/2/2023	-0.17	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.00
4/3/2023	-0.17	0.28	-0.61	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.20
4/4/2023	-0.17	0.28	1.00	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.33
4/5/2023	-0.17	0.28	4.72	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.33
4/6/2023	-0.17	0.28	6.06	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.10
4/7/2023	-0.17	0.28	7.21	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.08
4/8/2023	-0.17	0.28	8.08	1.00	0.50	0.00	0.50	0.50	0.50	0.50	0.00
4/9/2023	-0.17	0.28	9.57	1.00	0.50	0.00	0.50	0.42	0.50	0.50	0.10
4/10/2023	-0.17	0.17	9.28	0.92	0.50	0.00	0.50	0.33	0.33	0.50	0.00
4/11/2023	-0.17	0.06	8.89	0.70	0.75	0.00	0.50	0.00	0.00	0.50	0.10
4/12/2023	-0.17	0.17	9.28	0.83	0.67	0.00	0.50	0.25	0.33	0.50	0.00
4/13/2023	-0.17	-0.17	9.65	0.90	0.50	0.00	0.50	0.10	0.50	0.50	0.00
4/14/2023	-0.17	-0.17	10.46	0.83	0.50	0.00	0.50	0.25	0.50	0.50	0.00
4/15/2023	-0.17	-0.17	11.35	0.75	0.50	0.00	0.50	0.08	0.50	0.50	0.00
4/16/2023	-0.17	-0.17	11.85	0.80	0.50	0.00	0.50	0.00	0.50	0.50	0.00
4/17/2023	-0.17	-0.17	11.25	0.83	0.50	0.00	0.50	0.00	0.50	0.50	0.00
4/18/2023	-0.17	-0.17	10.28	0.75	0.50	0.00	0.50	0.08	0.50	0.50	0.00
4/19/2023	-0.17	-0.17	10.25	0.80	0.50	0.00	0.50	0.20	0.50	0.50	0.00
4/20/2023	-0.17	-0.17	11.44	0.83	0.50	0.00	0.50	0.00	0.50	0.50	0.00
4/21/2023	-0.06	-0.17	12.69	0.83	0.50	0.00	0.50	0.00	0.33	0.50	0.00
4/22/2023	3.24	0.06	13.49	0.70	0.50	0.00	0.50	0.00	0.10	0.50	0.00
4/23/2023	6.42	0.17	14.26	0.58	0.50	0.00	0.50	0.00	0.00	0.50	0.00
4/24/2023	3.94	0.17	13.31	0.58	0.50	0.00	0.50	0.00	0.08	0.50	0.00
4/25/2023	1.28	-0.17	12.69	0.60	0.50	0.00	0.50	0.00	0.00	0.50	0.08
4/26/2023	0.61	0.06	13.88	0.50	0.58	0.00	0.50	0.00	0.00	0.50	0.00
4/27/2023	0.28	0.17	13.21	0.50	1.10	0.00	0.40	0.00	0.00	0.50	0.08
4/28/2023	0.50	0.17	7.43	0.50	1.67	0.00	0.50	0.00	0.00	0.50	0.00
4/29/2023	7.11	0.17	3.10	0.50	2.08	0.00	0.42	0.00	0.00	0.50	0.25
4/30/2023	10.99	0.28	2.04	0.50	2.40	0.00	0.10	0.00	0.00	0.58	4.33

Date	North Saddle	South Saddle	Red Lassic	Black Rock 1	Black Rock 2	Bug Creek Butte 1	Bug Creek Butte 2	Dry Lake 1	Dry Lake 2	Red Mountain 1	Red Mountain 2
5/1/2023	10.58	0.28	1.28	0.50	1.75	0.00	0.17	0.00	0.08	1.30	3.20
5/2/2023	8.68	0.06	3.10	0.50	0.75	0.00	0.25	0.00	0.42	1.50	2.42
5/3/2023	9.74	-0.17	9.56	0.50	0.50	0.00	0.50	0.00	0.50	4.67	5.83
5/4/2023	12.08	-0.17	11.35	0.50	0.50	0.00	0.42	0.00	0.42	3.90	3.90
5/5/2023	14.32	0.06	12.14	0.50	0.50	0.00	0.50	0.00	0.17	3.25	2.67
5/6/2023	12.81	-0.17	12.01	0.50	0.50	0.00	0.30	0.00	0.20	3.33	3.33
5/7/2023	9.65	-0.17	13.38	0.50	0.50	0.00	0.42	0.00	0.50	5.00	5.00
5/8/2023	10.35	-0.06	14.74	0.58	0.50	0.00	0.25	0.00	0.33	2.25	2.00
5/9/2023	11.72	-0.06	15.71	0.50	0.50	0.00	0.50	0.00	0.30	4.50	5.50
5/10/2023	12.99	-0.06	14.08	0.50	0.50	0.00	0.33	0.00	0.08	8.20	9.10
5/11/2023	15.40	0.17	12.11	0.50	0.42	0.00	0.50	0.00	0.08	10.25	11.42
5/12/2023	16.96	0.17	13.38	0.50	0.40	0.00	0.10	0.00	0.00	12.83	15.00
5/13/2023	17.81	0.06	14.36	0.58	0.58	0.00	0.33	0.00	0.00	15.20	18.10
5/14/2023	17.63	0.17	14.93	0.50	0.80	0.00	0.40	0.00	2.92	16.17	18.75
5/15/2023	15.22	0.28	16.47	0.50	0.75	0.00	0.08	0.20	9.60	16.60	19.30
5/16/2023	16.38	0.28	17.53	0.50	2.42	0.00	0.17	6.08	11.00	17.83	20.00
5/17/2023	16.75	0.28	18.01	0.50	9.80	0.00	2.50	9.70	12.50	19.25	21.25
5/18/2023	15.89	0.28	18.11	0.67	11.25	0.00	7.75	10.83	12.83	20.60	22.70
5/19/2023	12.53	0.28	16.57	6.17	13.75	0.00	12.33	11.83	13.33	20.58	22.58
5/20/2023	8.53	0.28	15.89	11.90	15.30	0.00	14.00	12.60	14.30	21.50	23.58
5/21/2023	7.58	0.28	16.94	13.17	16.00	4.42	12.83	12.67	14.08	21.50	23.70
5/22/2023	9.93	0.28	15.99	12.92	15.00	9.33	12.17	13.33	14.33	20.75	22.75
5/23/2023	13.17	0.28	13.21	14.00	15.90	10.70	12.10	14.10	15.20	20.42	22.42
5/24/2023	15.11	0.28	9.72	14.17	15.58	12.50	12.83	14.00	14.67	18.80	20.90
5/25/2023	15.32	0.28	9.00	15.50	16.50	15.25	14.25	14.42	15.17	18.08	19.83
5/26/2023	16.08	0.28	10.56	16.80	17.80	17.20	16.30	15.00	16.00	16.92	18.42
5/27/2023	15.03	0.28	12.99	16.50	17.42	15.83	14.67	14.83	15.58	17.80	19.20
5/28/2023	16.47	0.28	14.85	16.92	17.83	16.67	16.17	14.42	14.25	18.92	20.67
5/29/2023	18.49	0.28	14.36	17.50	18.30	19.00	18.50	15.50	15.00	17.17	18.42

Date	North Saddle	South Saddle	Red Lassic	Black Rock 1	Black Rock 2	Bug Creek Butte 1	Bug Creek Butte 2	Dry Lake 1	Dry Lake 2	Red Mountain 1	Red Mountain 2
5/30/2023	19.56	0.28	15.11	17.92	19.00	18.83	17.92	15.67	15.75	16.90	18.40
5/31/2023	21.57	0.28	13.89	17.08	18.40	16.80	15.70	14.50	15.17	16.58	18.17
6/1/2023	23.11	0.28	14.82	16.70	17.50	15.67	15.00	14.70	15.60	18.00	19.50
6/2/2023	23.79	0.28	17.63	16.83	17.83	16.67	15.92	15.00	15.83	19.08	20.75
6/3/2023	22.81	1.58	19.17	18.90	20.00	18.70	17.90	16.70	17.60	20.75	22.50
6/4/2023	21.76	7.14	20.79	20.08	21.50	20.00	19.58	18.42	18.83	20.60	22.30
6/5/2023	20.21	9.47	21.94	19.92	21.08	20.50	20.25	19.25	19.17	19.67	21.25
6/6/2023	18.40	10.96	22.43	20.40	21.10	20.80	20.80	18.80	19.60	21.50	23.00
6/7/2023	16.85	10.97	22.22	17.92	18.75	17.58	17.75	15.83	16.00	18.70	20.20
6/8/2023	13.60	11.57	21.94	18.25	18.83	17.42	17.08	15.42	15.50	16.67	17.75
6/9/2023	11.76	13.57	20.99	18.10	18.60	19.90	18.60	15.50	16.50	20.08	21.25
6/10/2023	12.58	15.03	19.44	18.92	19.58	19.67	18.67	16.75	17.17	20.70	21.90
6/11/2023	11.19	15.99	17.14	20.50	21.83	20.25	19.42	17.83	17.33	19.75	20.83
6/12/2023	13.38	18.13	13.99	21.90	22.90	22.50	21.20	19.10	19.20	20.67	21.92
6/13/2023	14.93	18.51	12.25	21.58	22.67	21.42	20.42	18.50	19.25	20.90	22.00
6/14/2023	14.56	18.90	11.83	20.50	21.67	20.50	19.25	19.50	19.25	21.83	23.33
6/15/2023	14.71	19.58	11.10	21.20	22.50	21.50	20.10	19.60	20.30	22.67	24.33
6/16/2023	18.99	20.22	11.96	21.92	23.25	22.33	21.00	19.67	20.17	23.70	25.50
6/17/2023	21.76	19.85	12.54	21.58	23.50	22.00	20.60	20.25	20.42	22.58	24.17
6/18/2023	23.93	18.22	12.64	19.20	20.42	17.58	16.83	17.20	18.30	20.20	21.80
6/19/2023	24.97	11.00	12.50	12.33	12.92	10.67	10.83	12.25	12.67	15.67	17.00
6/20/2023	26.04	10.90	15.89	13.70	13.40	10.80	11.10	12.40	12.60	16.25	17.50
6/21/2023	25.25	15.31	19.46	15.83	16.08	14.42	14.33	14.58	15.25	18.90	20.60
6/22/2023	25.06	15.90	21.67	18.08	18.33	17.08	16.50	16.08	16.25	19.00	20.50
6/23/2023	22.13	17.64	22.92	19.40	19.80	19.60	18.20	16.80	17.50	20.33	21.75
6/24/2023	21.67	19.08	23.78	19.33	20.25	17.75	17.00	17.75	17.50	18.60	20.20
6/25/2023	24.00	18.68	23.39	19.08	19.17	18.75	19.25	17.67	18.17	15.92	16.92

Appendix D. Soil characteristics from all four study sites alongside the mean of 10 soil samples (found in Appendix E) collected from occupied Lassics lupine habitat within the Lassics with one sample from each site; all elemental concentrations were extractable with the exception of Cr and Ni (total concentrations); Lassics lupine soils data were obtained from Imper (2012) with the exception of Ni and Cr data obtained from Alexander (2008), indicated with an asterisk.

	Dry Lake	Bug Creek Butte	Red Mountain	Black Rock	Lassics (mean)
pH	5.9	5.4	5.8	6.7	6.4
P ppm	3.6	2.7	6.0	6.2	8.9
K ppm	45.0	51.0	34.0	31.0	43.2
Ca meq 100g	3.1	4.6	4.0	1.0	1.3
Mg meq 100g	4.8	1.1	8.0	5.5	5.0
Cu ppm	0.7	0.6	1.3	0.8	1.3
Mn ppm	6.3	0.8	7.6	11.6	11.4
Fe ppm	46.7	21.4	63.0	58.8	61.3
Zn ppm	0.5	0.2	0.7	1.3	0.7
NO3 N ppm	0.8	0.8	4.4	2.4	0.7
OM LOI	2.5	0.7	2.8	2.5	6.1
Total % C	1.4	0.4	1.6	1.5	1.1
Ca Mg ratio	0.6	4.2	0.5	0.2	0.4
% Sand	70.0	75.0	65.0	46.9	81.0
% Silt	15.0	15.0	17.5	30.6	14.3
% Clay	15.0	10.0	17.5	22.5	4.9
Na ppm	22.0	19.0	8.0	9.0	5.2
Cd ppm	0.6	0.3	0.4	0.5	0.1
B ppm	<0.1	<0.1	<0.1	<0.1	0.1
Pb ppm	2.0	11.2	0.5	2.0	0.2
Cr ppm	1110.6	44.8	697.2	327.8	414.92*
Ni ppm	1528.3	40.5	913.9	2204.7	475.92*
Mo ppm	1.6	0.6	0.7	0.9	<0.05
As ppm	0.6	4.9	0.6	0.5	<0.05

Appendix E. Soil characteristics from 10 soil samples collected from occupied Lassics lupine habitat within the Lassics with one sample from each site; all elemental concentrations were extractable with the exception of Cr and Ni (total concentrations); all Lassics lupine soils data were obtained from Imper (2012) with the exception of Ni and Cr data obtained from Alexander (2008), indicated with an asterisk.

	Red Lassic Open Slope	Red Lassic Canopy	Signal Peak 1	Signal Peak 2	Signal Peak 3	Signal Peak 4	Saddle 1	Saddle 2	Saddle 3	Swale
pH	6.4	6.3	6.2	6.4	6.3	5.7	6.8	6.7	6.3	6.7
P ppm	6.0	5.0	4.0	5.0	14.0	31.0	5.0	8.0	7.0	4.0
K ppm	61.0	51.0	51.0	27.0	55.0	36.0	45.0	35.0	29.0	42.0
Ca meq 100g	1.0	1.3	0.8	1.0	2.1	1.1	1.0	2.0	1.5	1.1
Mg meq 100g	8.2	6.6	5.0	4.7	5.3	0.8	4.2	3.8	4.2	7.1
Cu ppm	1.7	1.2	1.1	1.0	1.4	1.2	1.4	1.7	1.1	1.2
Mn ppm	36.5	14.0	13.8	2.6	5.8	1.8	3.8	3.5	12.1	20.4
Fe ppm	88.0	91.9	68.8	41.6	51.8	26.4	26.3	26.5	84.2	107.3
Zn ppm	0.8	0.8	0.6	0.4	0.9	0.3	0.7	0.7	0.7	0.8
NO3 N ppm	0.7	0.3	0.2	0.5	1.3	0.9	1.1	0.3	0.8	0.6
OM LOI	8.9	7.2	7.0	7.7	6.9	4.4	3.0	4.6	6.2	5.0
Total % C	1.9	1.7	1.1	0.5	1.1	0.7	0.5	0.5	0.6	2.0
Ca Mg ratio	0.1	0.2	0.2	0.2	0.4	1.4	0.2	0.5	0.4	0.2
% Sand	37.0	86.0	85.0	86.0	81.0	91.0	86.0	90.0	86.0	82.0
% Silt	41.0	11.0	11.0	11.0	14.0	6.0	12.0	10.0	12.0	15.0
% Clay	22.0	3.0	4.0	3.0	6.0	3.0	2.0	1.0	2.0	3.0
Na ppm	8.3	5.5	4.1	4.6	4.7	3.3	4.5	6.0	5.2	6.0
Cd ppm	0.1	<0.05	<0.05	<0.05	0.1	0.1	<0.05	<0.05	0.1	<0.05
B ppm	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Pb ppm	0.4	0.2	0.1	0.1	0.1	0.2	0.1	0.2	0.2	0.3
Cr ppm	1284*	1284*	<0.05	691*	<0.05	93*	797*	<0.05	<0.05	<0.05
Ni ppm	1334*	1334*	<0.05	925*	<0.05	101*	1065*	<0.05	<0.05	<0.05
Mo ppm	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
As ppm	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Appendix F. Summary of plant families and species counts observed during field work at all four study sites and surrounding 0.8 ha (2 ac) habitat. A total of 42 families and 110 species were documented.