DISTRIBUTION AND HABITAT REQUIREMENTS OF DESERT YELLOWHEAD (*YERMO XANTHOCEPHALUS*), FREMONT COUNTY, WYOMING

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ABSTRACT

Yermo xanthocephalus (desert yellowhead) is a narrow endemic originally known from one population in Fremont County, Wyoming and listed as Threatened under the Endangered Species Act. The original hypothesis was that *Yermo* is a habitat specialist restricted to exacting environmental conditions not found elsewhere on the landscape. Two sets of techniques were used to identify potential habitat, including photointerpretation and four different approaches in potential distribution modeling. This study has refuted the original hypothesis in documenting a second population under contrasting soils and vegetation conditions. At least nine of the seventeen soil parameters that were measured differ between the original *Yermo* population and the new *Yermo* population, including relatively high potassium, and high silt content. Soils of the two *Yermo* populations differ in as many or more soil properties as they do with the two other sample sets. The grass-dominated vegetation of the second *Yermo* population is distinct from the original *Yermo* population with its sparse, cushion plant community, and from the surrounding sagebrush steppe. If *Yermo* is not restricted by narrow soils and vegetation requirements, then alternative explanations of its limited distribution need to be tested, possibly involving dispersal and germination ecology.

ACKNOWLEDGEMENT

The monitoring and status work on *Yermo xanthocephalus* (desert yellowhead) by Richard and Beverly Scott is reflected throughout this document. They collected soils in this and all *Yermo* soils research studies to date, and provided their previous monitoring grid, their previous survey routes, and insights. This work also draws from the publications of Robert Dorn, and the status report of Walter Fertig as previous Wyoming Natural Diversity Database Botanist, whose works are also basic to current understanding.

University of Wyoming Soils Testing Laboratory, Laramie, WY, provided soils analysis under coordination of Ramona Belden.

Annie Munn (Wyoming Natural Diversity Database; WYNDD) digitized all past and present survey routes, and helped compile field results. George Jones and Al Redder (WYNDD) provided PC-ORD support. Gary Beauvais (WYNDD) provided review of a report draft.

Steve Williams (Department of Renewable Resources, University of Wyoming) provided statistical design concepts and interpretation of the soils data, and Brent Ewers (University of Wyoming) provided photosynthesis measurements and results.

The current status of *Yermo* status reflects the collective work of agency biologists including Mary Jennings and Jan McKee for U.S. Fish and Wildlife Service (FWS), and Connie Breckenridge, Jeff Carroll, Tyler Abbott, Chris Keefe, and last but not least, Adrienne Pilmanis, who coordinated the current project for Bureau of Land Management (BLM). This research was conducted as a challenge cost-share project between the BLM State Office and WYNDD – University of Wyoming.

Table of Contents

FIGURES AND TABLE

APPENDIX

INTRODUCTION

Desert yellowhead (*Yermo xanthocephalus*; hereafter referred to as *Yermo*) was discovered in 1990 by Robert Dorn, and published as a new genus and species by him the following year (Dorn 1991). It was known from a single population. Concerted inventories were conducted in the vicinity to search for new populations (Fertig 1995). A potential distribution model was produced that identified potential habitat for it in an eight-county area (Fertig and Thurston 2001), and surveys were expanded without finding new populations (Heidel 2002). It was listed as Threatened because surface disturbances associated with oil and gas development, compaction by vehicles, trampling by livestock, and randomly occurring catastrophic events were considered threats to the existing population (USDI Fish and Wildlife Service 2002). Critical habitat was later designated to protect the ecosystem on which it depends (USDI Fish and Wildlife Service 2004).

There is a draft conservation strategy for the species (USDI BLM 1998), a 20-year mineral withdrawal and emergency road closure for its habitat (USDI BLM 2005 a, b), a biological opinion by the U.S. Fish and Wildlife Service (2005) that reviewed the BLM Lander Resource Management Plan, and an outline for recovery prepared by the U.S. Fish and Wildlife Service (2010) as a preliminary course of action. The latter outline identified the need for determining the ecological requirements of *Yermo*, including soil, water, and topography, and revision of its potential distribution model accompanied by field surveys, and other needs.

Scott and Scott (2009) documented population trends while also providing the most complete documentation of *Yermo* environmental setting, climate, species' biology and life history. Their work is the foundation for identifying the unique characteristics of its environment, as needed to ensure that all suitable habitats were surveyed and habitat requirements met. In turn, the current study was designed to:

1. Use digital aerial photographs to identify possible survey gaps, employing multiple working hypotheses regarding *Yermo* habitat requirements compared against past *Yermo* survey routes.

2. Use current modeling techniques and software, and new remote sensing themes to prepare new potential distribution models and identify possible survey gaps compared against past *Yermo* survey routes.

3. Employ all the information and resources above in conducting new surveys.

4. Determine characteristics of *Yermo* habitat in the process of determining ecological requirements, by documenting the associated soils and vegetation, and describing and differentiating occupied habitat from unoccupied habitat. Soil sample and vegetation plots were taken from all segments of *Yermo* habitat, from superficially similar barren habitat ("Potential"), and from surrounding sagebrush steppe ("Steppe").

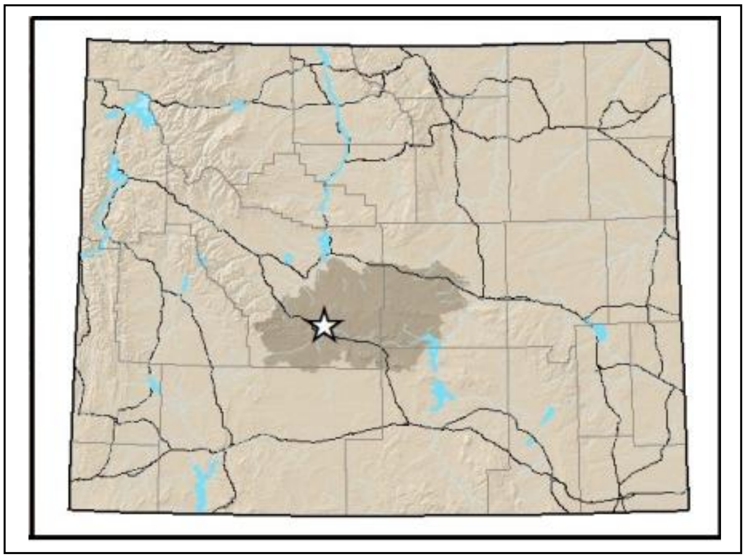
The hypothesis was that *Yermo* is a habitat specialist limited to exacting conditions found only at one site. The four study objectives are addressed in four separate chapters, though each informed the other. The two office tasks (above) were overlapping, as were the two field tasks.

STUDY AREA

Location and Setting

The study area is centered on the original site where *Yermo* was discovered near the Beaver Rim of Fremont County, Wyoming (Figure 1). The Beaver Rim is an extensive east-west Tertiary basin fill remnant (McMillan et al. 2006) at the juncture of the Sweetwater Valley and Wind River Basin physiographic regions. The study area encompasses the entire Beaver Rim and a watershed-based set of units (Figure 1). Its delimitation is discussed in Chapter 2.

Figure 1. *Yermo* study area within Wyoming



Yermo habitat lies in barren outwash at the base and lower slopes of a highly-eroded, south-facing escarpment, forming slightly bowl-shaped depressions. The eroding escarpment slopes are at the interface of the White River (late Eocene-Oligocene) and overlying Split Rock (Oligocene-Miocene) Formations, and the parent material of outwash is mainly from the former. The four characteristics of this setting - topographic position, aspect, microtopography, and erosion process - have been the main but not the only characteristics used in past *Yermo* surveys.

More detailed physical and biological characteristics of occupied *Yermo* habitat are reported by Fertig (1995) and (Heidel 2002), and greatly expanded by Scott and Scott (2009). Detailed information has also been collected on climate at the original site where *Yermo* was discovered, and highlighted by Scott and Scott (2009).

Soils

Yermo grows in a shallow, loamy soil of the Entisol order (paralithic contact at 33 cm), classified as a coarse-loamy over sandy-skeletal, mixed, Lithic Torriorthent. By contrast, the adjoining sagebrush steppe has a deep (117 cm+) sandy loam of the Aridisol order (Bynum 1993). The *Yermo* setting appears to be influenced by wind, with soft sedimentary deposits weathered in place having provided the parent material for the weakly developed soils. The immature nature of the soil is evidenced by an ochric epipedon and the lack of diagnostic subsurface horizons, with no evidence of illuvial accumulations of humus, clay, gypsum, salts, or carbonates. Pans and residual accumulations of iron or aluminum oxides are absent, and there was no formation of peds (Bynum 1993).

Scott and Scott (2009) cite Van Houten (1964) in describing the parent material as "volcanic facies…(of) yellowish-gray to light-gray calcite-cemented, volcanic sandstone and tuff interbedded with conglomerate containing angular to subround Tertiary volcanic rocks." *Yermo* soils are mapped as members of the Cragosen-Rock outcrop-Carmody complex, classified as Lithic and Ustic Torriorthents (Scott and Scott 2009).

Richard Scott, Beverly Scott and Kent Houston collected 12 soil samples from three areas in 2000 and 2001, including soils in *Yermo* habitat, soils similar to *Yermo* habitat but not occupied, and soils from adjoining well-vegetated sagebrush steppe habitat. Scott and Scott (2009) determined water retention capacity, organic matter loss on ignition, CaCO3 equivalents, pH, and % sand, % old/new clay, and % old/new silt, in addition to placing each sample into a soil texture class and Munsell soil color class. They identified five slight though significant differences between *Yermo* habitat soils and adjoining soils that have high vegetation cover. The last three characteristics are related to one another:

1) Higher silt content (44.6 vs. 38.6 %)
2) Slightly higher alkalinity (pH of 7.89 vs. 7.3)
3) Slightly lighter color (10YR7/3 vs. 10YR6/3)
4) Lower loss on ignition organic matter (4.3 vs. 5.4 %)
5) Lower water retaining capacity (48.0 vs. 54.9 @ 1500 mpa)

Vegetation

Vegetation in occupied *Yermo* habitat is sparse, at generally less than 10% cover, with a major contribution by cushion plants (Fertig 1995). It is has an abrupt border with surrounding sagebrush steppe. Scott and Scott (2009) provided greatly expanded vegetation and related floristics documentation. They sampled vegetation in square-meter sample plots across *Yermo* habitat (n=34) and adjoining non-*Yermo* habitat dominated by woody sagebrush (n=28) using the relevé method (Benninghoff 1966). The floristic composition was also documented by collecting voucher specimens extensively in occupied and unoccupied habitat to compile a master list of species across the landscape (Appendix 4 in Scott and Scott 2009). They report a comparatively rich flora for the small area occupied by *Yermo* despite the sparse cover, encompassing 21 families, 68 genera, and 105 species based on floristic studies. Of the 278 species on the master list, 30 were found only at the *Yermo* site. The original plot data was made available for this project as presence/absence data.

CHAPTER 1. PHOTOINTERPRETATION

Background

Aerial photography provides a way to understand the visual patterns associated with occupied *Yermo* habitat and its position on the landscape. Features that may not be apparent at eye level may be conspicuous from the air and at different scales. Digitized orthophotographs, in particular, provide the researcher a tool to integrate detailed population mapping with different Geographic Information Systems (GIS) themes and high-resolution imagery at varying scales.

Occupied *Yermo* habitat shows patterns on digital orthophotographs that correspond with those discerned in the field. The low topographic position is indicated by the adjoining escarpment highlighted in shadows. The microtopography is indicated by lighter shadows. Aspect is indicated by imagery orientation. Erosion processes are suggested by water tracks radiating from the base of outcrops. In addition, the sparseness of the vegetation and light soil color are apparent in the high reflectance, approaching white. Photointerpretation is suited for systematic review of potential habitat over large areas and applying different combinations of habitat attributes to identify potential habitat.

Methods

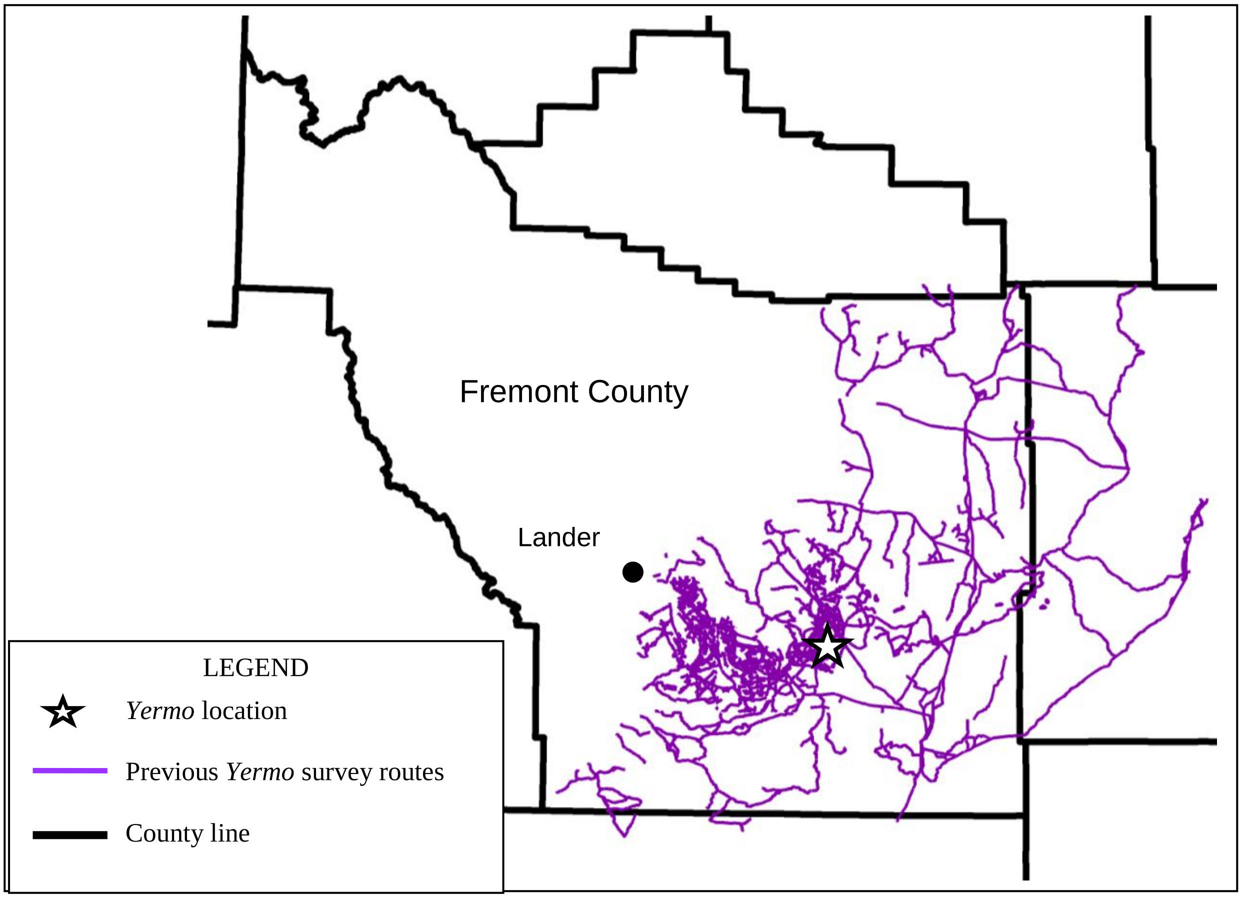
Photointerpretation was initiated using digital orthophotographs that covered Fremont and Natrona counties (MrSID format, 1994 black-and-white), also including Sublette County at early stages. Three tasks were conducted at the photointerpretation phase of work.

First, the *Yermo* population grid was digitized for reference. The original *Yermo* population was described as having three discrete subpopulations (Fertig 1995) based on boundaries that were drawn by hand during field surveys onto USGS topographic maps, and later digitized for entry in the database maintained by Wyoming Natural Diversity Database (WYNDD). Later, the population was mapped in precise grids as part of monitoring research (Scott and Scott 2009). A 30 ha grid encompassing the entire population was divided into hectare cells, and each cell was subdivided into 100 plots of 10 m x 10 m. *Yermo* was monitored in each 10 m x 10 m cell each year from 1995-2004 (except 1999). The geo-referenced corners and gridded map of occupied habitat was reconstructed in ArcMap using the survey corners and grid data, representing a highly-accurate map of the three subpopulations and outliers, totaling an occupied area of 4.4 ha. The Scott and Scott (2009) mapping was compared against digital aerial photos, and all segments of *Yermo* distribution aligned with all linear and polygonal bare ground patterns seen on aerial imagery. This mapping was used in predictive modeling for sampling relevant environmental gradients within the documented occurrence boundaries. The most current mapping represents the population as five discrete polygons and five isolated points, adding two small polygons to the three original subpopulations, plus outlier plants (Appendix A). This detailed mapping was used in photointerpretation and predictive distribution models, and is submitted as a GIS product.

Second, all past survey routes were digitized to identify survey gaps. The original discovery of *Yermo* spurred a flurry of surveys. Survey routes are represented in the first *Yermo* status report showing survey routes of Robert Dorn, its original discoverer, and of Walter Fertig (Fertig 1995). Surveys were conducted on foot, and the routes marked onto USGS 7.5’ topographic maps. A later status report update was prepared for *Yermo* based on surveys over an expanded eight-county survey area (Heidel 2002), also conducted on foot and drawn onto USGS 7.5’ topographic maps, with limited work in Fremont County. Finally, a *Yermo* monitoring report was produced by Richard and Beverly Scott that represented their monitoring work and related research (mentioned but not presented in Scott and Scott 2009). Their surveys from ATV spanned more years and covered greater distances than all of the rest combined. They made their original survey routes available for this project, as marked onto BLM 1:100,000 surface management maps and digitized at WYNDD.

All *Yermo* survey routes were digitized as lines onto digital raster graphics (DRGs) of topographic maps in three separate themes that correspond with the three reports. All digitizing was done in ArcMap. Overlays of these survey routes were taken to represent the collective *Yermo* survey effort to date. These linear survey routes are assumed to cover potential habitat at least 10 m on either side of the route, targeting the most suitable habitat, focusing on barren habitat. A composite map of all survey routes along Beaver Rim covers the eastern third of Fremont County and adjoining Natrona County (Figure 2). Survey routes were used for reference in photointerpretation, and are submitted as GIS products.

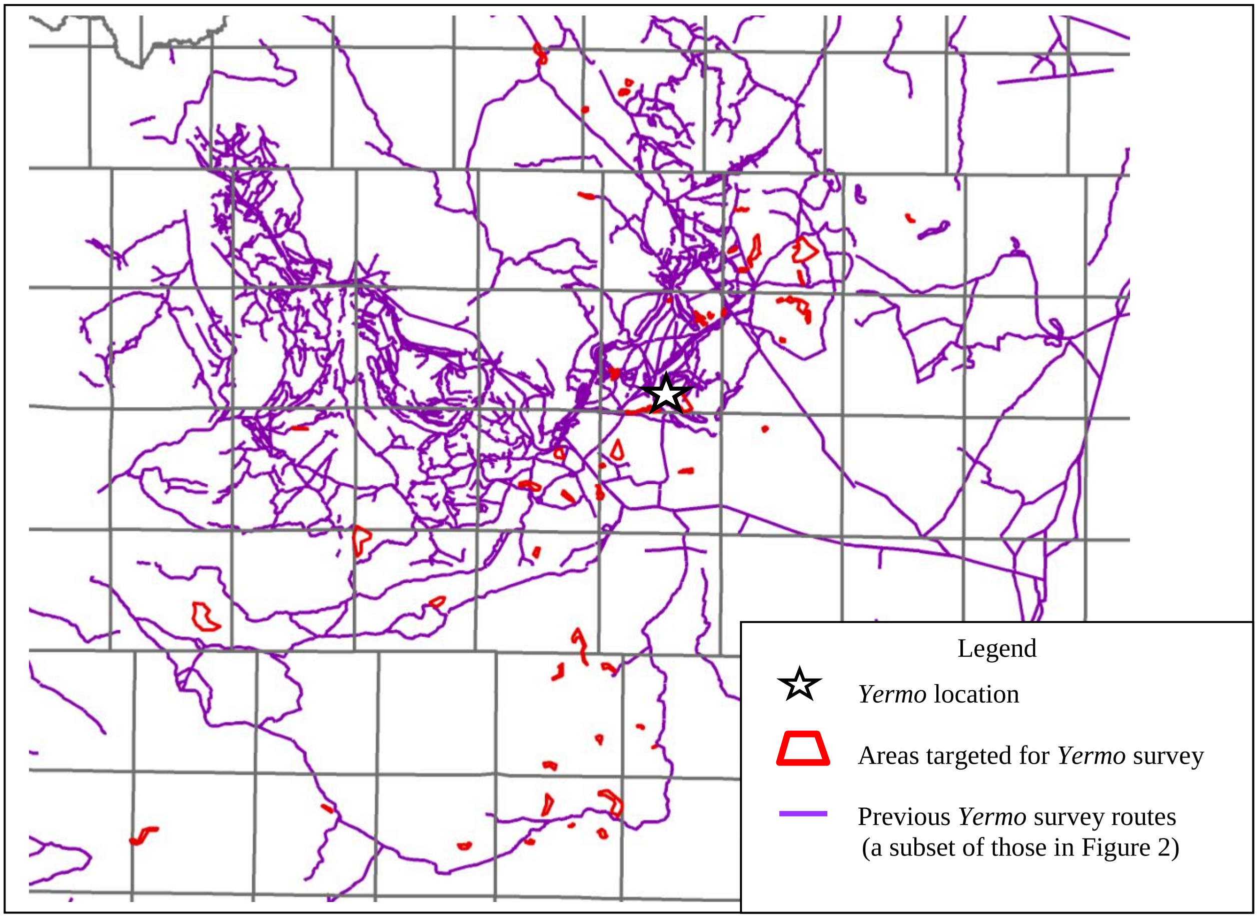
Figure 2. Past *Yermo* survey routes in Fremont County or adjoining counties, including those reported by Scott and Scott (personal communication), Fertig (1995), and Heidel (2002).



Third, aerial imagery covering all intermontane terrain was visually screened across the three-county area at 1:24,000, spanning over 100 USGS 7.5' topographic quadrangles in the Beaver Rim study area, and over 20 in the Upper Green River. The quad boundaries and section lines were superimposed for systematic review section-by-section in each quarter-quad. Digital layers representing past survey routes were superimposed, and areas were ruled out from future survey if they were previously surveyed.

In each map, areas of sparsely-vegetated habitat were identified, zooming in for closer review at 1:4,000, looking primarily for areas that strongly resembled occupied *Yermo* habitat (sparsely-vegetated hollows at the base of ridges and escarpments). Next, any large areas of sparsely-vegetated upland habitat that had not been surveyed to date were identified. The final product was a set of digitized polygons that were drawn to encircle areas on digital orthophotographs that met one or more habitat criteria and lacked survey.

Figure 3. Areas targeted for new *Yermo* surveys based on photointerpretation. (Townships are included for scale.)



Results

Forty polygons were drawn as survey targets, spanning 20 townships (Figure 3). They included both Sweetwater Valley and Wind River Basin physiographic settings. Maps of the survey routes and a table of survey site characteristics are provided in Appendix A. Polygonal survey targets were printed out at 1:24,000 on 8 ½ x 11" paper so that they could be used interchangeably with USGS topographic maps for navigation to potential habitat. There was a total of 20 quarter-quad printouts. Section lines and private lands were superimposed for reference. An example of the polygon targets superimposed onto an aerial photograph as a quarter-quad printout is included in Appendix A.

One of the forty polygons was found to harbor a second, new *Yermo* population. The setting of the second population was not on an outwash, but was on an escarpment slope. A tabulation of all sites surveyed and the survey routes are presented in Appendix A. These survey routes are added to the compilation of negative surveys submitted as a separate GIS product.

Discussion

The availability of digitized survey routes drew from the survey results of all botanists conducting surveys in the past. The overlay of survey routes onto digital orthophotographs for identifying potential habitat that had not been surveyed were effective ways to consider the full range of unsurveyed potential habitat.

The original study design of this one-year project took on a new opportunity and challenge with discovery of a new *Yermo* population in 2010 as a result of photointerpretation, modeling and surveying work. This population is referred to throughout the rest of the report as the "new" population or the "second" population, in contrast to the "original" or the "first" population.

CHAPTER 2. PREDICTIVE DISTRIBUTION MODEL

Background

Predictive species distribution models are typically generated by sampling the values of relevant environmental gradients at documented occurrence locations for the species, then statistically extrapolating these gradients across the landscape to identify areas with relatively similar environmental characteristics (e.g., Elith et al. 2006, Greaves et al. 2006, Phillips et al. 2006, Guisan and Thuiller 2007). The use of predictive distribution models provides ease of integrating multiple environmental factors that let available distribution data produce the best fit. As with any exercise in modeling, the quality and robustness of the distribution model output is directly related to the quality of the input data: specifically, the accuracy, reliability, and quantity of occurrence locations available for modeling.

The *Yermo* models produced by Fertig and Thurston (2001, 2003) treated the existing population as a single point. The values for twelve continuous environmental predictor layers and four categorical predictor layers were sampled at this location. A range of values was created around the observed continuous value by adding and subtracting 10% from the sampled value for each continuous predictor variable. Each continuous predictor layer was then classified as suitable where its values fell within these ranges. Categorical predictors were classified as suitable where they had the same value(s) as those observed within the mapped populations. Finally, a multiplicative overlay was done to generate a model layer classified as suitable where the values fell within the suitable ranges or classes for all predictor layers. Given the methods used, and the single sample, confidence in the model output was low.

All areas of high probability and medium probability identified in any of the three predictive distribution models (described later) were screened a second time to add ensure completeness, and a subset of polygons were culled. Barren habitats within them were identified by digitizing polygons as initiated in photointerpretation. This approach enabled researchers to pursue multiple working hypotheses of what constitutes suitable *Yermo* habitat using the three different models and excluding models but going strictly with one or more habitat attributes.

Methods

With only a single population to use as training data for modeling, we explored the following approaches for generating more robust models:

1) Overlaying existing distribution models for narrowly-distributed species associated with *Yermo* (i.e., species that co-occur with and appear to use similar habitats as *Yermo*),
2) Sub-sampling the occupied *Yermo* polygons, using the most detailed and accurate mapping of its subpopulations, to provide multiple input points, in an attempt to reduce inaccuracy and overfitting,

3) Including new environmental data layers that may represent better information about the habitat requirements for the species, and

4) Using a newer algorithm that can generate useful models with relatively few occurrence points.

Four models were produced and they are described further in the following sections. The first three of these models were available in time to incorporate into photointerpretation work. They were projected onto digital orthophotographs and all areas having one or more attributes potentially corresponding to *Yermo* habitat were identified and polygons drawn to identify survey targets. These steps were linked to photointerpretation without models, and at least 10% of the 40 polygons targeted for survey would not have been targeted if not for models.

Species Intersection Model

Whereas *Yermo* was known from only a single population, two other state endemic species that appear to be close associates of *Yermo*, *Cirsium pulcherrimum* var. *aridum* (*Cirsium aridum*; Cedar Rim thistle) and *Phlox pungens* (Beaver Rim phlox) were known from approximately 19 and 40 locations, respectively. *Cirsium pulcherrimum* var. *aridum* was identified as a frequent associate of *Yermo* in square-meter quadrats sampled in both *Yermo* and non-*Yermo* habitat (Scott and Scott 2009). *Phlox pungens* is found on the ridgetop directly above occupied *Yermo* habitat (*Dorn 5052*). Both of these species were modeled previously (Fertig and Thurston 2003) using a classification and regression tree (CART) approach, and the resulting models were given values of 0 (predicted absent), 1 (low probability of occurrence), 2 (medium probability of occurrence), and 3 (high probability of occurrence). These Fertig and Thurston (2003) models were based on more presence locations and more robust methods than was the *Yermo* model by the same authors, and the two species appeared to be associated with *Yermo*, so we felt that they might contain useful information about the distribution of *Yermo*. As such, we generated a model for *Yermo* by an additive overlay of the models for *P. pungens* and *C. pulcherrimum* var. *aridum*. The resulting model is not so much a prediction of *Yermo* distribution as it is a prediction of overlap in the distribution of the two associated species. It is referred to hereafter as the "species intersection model," and had values ranging from 0 (neither *P. pungens* or *C. pulcherrimum* var. *aridum* predicted to occur) to 6 (high predicted probability of both *P. pungens* or *C. pulcherrimum* var. *aridum* occurring).

Maxent Models

A relatively recent development in species distribution modeling is the Maximum Entropy algorithm (“Maxent”; Phillips et al. 2004), used to predict probability of occurrence based on presence-only data. This algorithm has been shown to produce useful models even when relatively few presence points are available for training (Hernandez et al. 2006). We generated Maxent models at both a statewide and regional extent, using occurrence data from the known population and a total of 24 environmental variables that were developed to represent habitat conditions across Wyoming (for vertebrate models by Keinath et al. 2010; Appendix B).

Statewide Maxent Model

The subpopulations of *Yermo* were mapped as distinct polygons in the gridded monitoring system of Richard Scott (see preceding chapter on photointerpretation). We used a free extension to ArcMap, Hawth's Tools (Beyer 2004) to generate ten sets of three random points within the polygons (one point per polygon). This sub-sampling and subsequent jackknife approach was used, rather than using a single centroid to represent each polygon, to reduce the possibility that, through chance, the values of the predictor data at the location of a polygon's centroid were not representative of the conditions required by the species. This resulted in ten sets of three points, each of which were attributed with values from the environmental predictor layers generated by Keinath et al. (2010). Maxent models were then generated for each set of subpopulation samples using the full set of potential predictors.

The importance of each predictor across all ten models was evaluated by reviewing three statistics provided by Maxent (Phillips no date): 1) the "Percent Contribution" value; 2) the "Gain With Only Variable" value; and, 3) the "Gain Without Variable" value. "Gain With Only Variable" values provide an indication of which variables contain the most information *by themselves* about the species' distribution; "Gain Without Variable" value indicate which variables contain the most information *not contained in other variables* about the species' distribution. Percent Contribution is a blending of these "Gain Without" and "Gain With Only" statistics. Finally, the variables that scored well by these three statistics were reviewed to identify those variables that are most biologically relevant (using variables identified by Fertig 1995, Scott and Scott 2009), in some cases substituting similar variables we felt were more meaningful than those selected by the Maxent statistics (e.g., substituting "bare ground cover" in place of the less biologically meaningful "deciduous forest cover"). This resulted in a set of eleven variables that would provide the best statewide model.

To generate the final statewide model, the eleven selected variables were used with the full set of thirty sub-samples in a single model. Functionally, Maxent used only sixteen of these subsamples, as the remainder represented duplicate values for the environmental predictors. The feature types used by Maxent were constrained to "Linear Only," and the regularization parameter, beta, to 1 for "linear-quadratic-product" features (Phillips no date). These adjustments to the settings were made to protect against overfitting that might otherwise occur due to the pseudo-replication created by sub-sampling. In effect, this method resulted in a model based on environmental gradients that are most representative of those found within the mapped polygons of the known population.

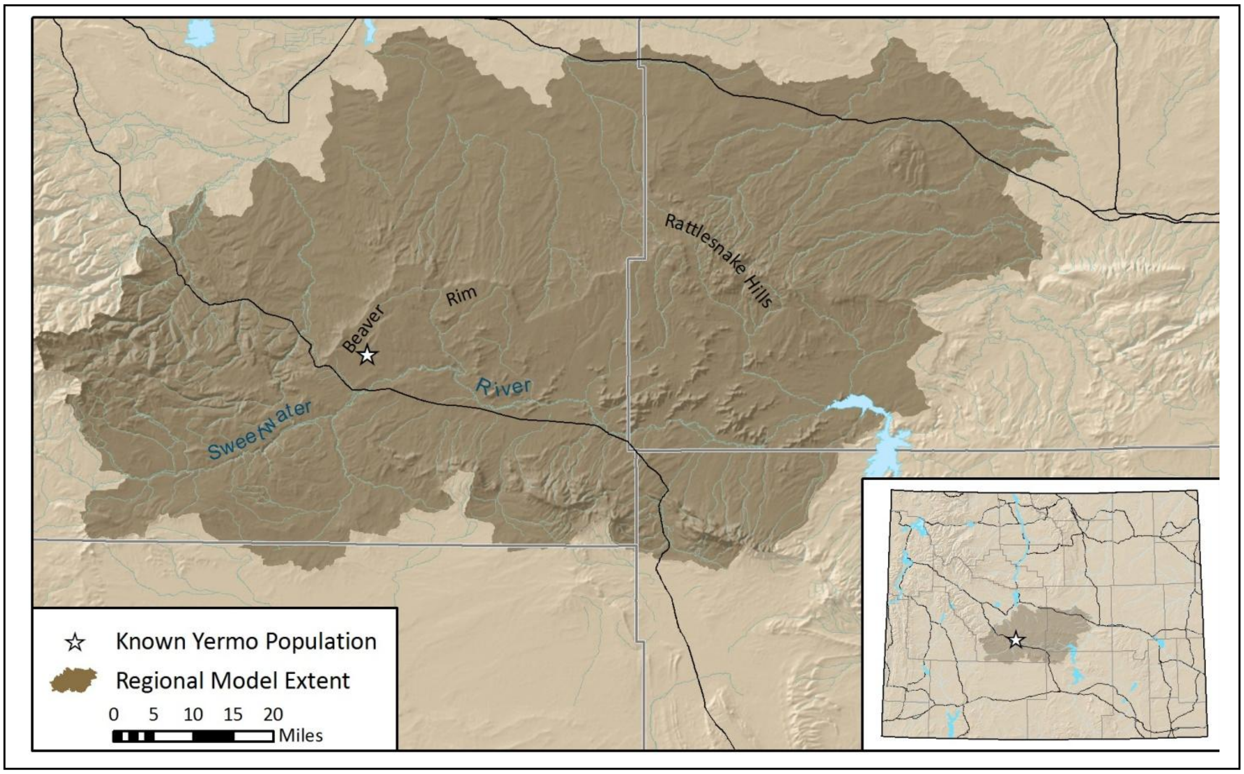
The resulting model was applied to the predictor layers to generate a final "logistic" format raster, representing the predicted probability of occurrence for the species, as floating point values ranging from zero to one. The "Minimum Training Presence" threshold (Phillips no date) suggested by Maxent was applied to generate a binary raster showing predicted absence and predicted presence.

Regional Maxent Model

Prior surveys were based on a draft statewide *Yermo* model (Fertig and Thurston 2001), which found no new populations of *Yermo*. Consequently, in addition to the new statewide model, a more localized model was generated that keyed in on the region surrounding the known population of *Yermo*, in the hope that it might be able to better resolve the finer-scale environmental variables linked to distribution of the species.

The regional model extent was set to encompass the Beaver Rim, where the known population was located, selecting and merging the 10-digit Hydrological Unit Code (HUC) boundaries (Simley and Carswell 2009) that intersect and surround the Rim (Figure 4). This encompasses two physiographic regions; the Beaver Rim marks the boundary between the Wind River Basin (to north), and the Sweetwater River valley (to the south).

Figure 4. Overview of regional model extent and previously known *Yermo* population.



Next, Hawth's Tools were used to generate 10,000 random points within this region, specifying a minimum separation of 30 m, to be used as background points for a regional Maxent model. These points were then attributed with the values for the environmental predictor layers. Then, a Maxent model was run that included all environmental predictors and all 30 sub-samples, using the same parameters used in the statewide model. Again, the "Percent Contribution," "Training Gain With Only," and "Training Gain Without" values were used in conjunction with knowledge of the species to select the variables that appeared to best predict *Yermo* distribution at the regional level. As with the statewide model, both the logistic-format output raster and the binary expression of this model were generated using the threshold metric, "Minimum Training presence."

Model Validation

The photointerpretation steps described in Chapter 1 were repeated for all areas of high probability in the three models (i.e., the Species Intersection model and the statewide and regional Maxent models) to ensure that sparsely-vegetated habitat identified by any of the three models was considered. By photointerpretation alone, and photointerpretation cross-referenced with models, all unsurveyed areas meeting these criteria were delimited by polygons and targeted for survey (total=40). The digital ortho quarterquads (doqqs) covering all such survey targets were printed out onto 8 ½" x 11" pages at about the same scale as USGS 7.5' topographic maps for ease of navigating to them and covering them systematically.

Following the collection of presence/absence data during the 2010 field survey, guided in part by the distribution models, ROC analysis (Fielding and Bell 1997) was used to identify a threshold (i.e., that which found the threshold which maximized the sum of specificity and sensitivity of the model relative to the field data), and this threshold applied to generate final, binary versions of each model. Model accuracy was assessed by comparing these binary predictions against the 2011 presence/absence data using a confusion matrix and common summary statistics.

Hybrid Model
A primary objective of modeling was to help locate new populations of *Yermo*, so the ultimate plan was to produce a model that restricted predictions to only the locations with the highest likelihood of being occupied by the species. This fourth model was not incorporated into study design until after fieldwork, as a synthesis and complementary product to survey results. It combines the predictions from the species intersection, statewide, and regional models into a single predictive distribution model (hereafter referred to as the "hybrid model"), by multiplying the values for each of the input rasters. The resulting model had possible values ranging from 0 (not predicted as occurring by any models) to 6 (predicted as highest possible probability of occurrence by all models). As with the previous models, ROC analyses were used to select an optimal threshold and the resulting binary model was evaluated using 2010 field survey data.

Results
Tests of the four distribution models are represented in Table 1, showing that only the integration of models represented by the Hybrid Model combines highest accuracy, sensitivity, and specificity.

Table 1. Results of Yermo potential models relative to validation data from 2010 surveys. Bold text indicates the best value for each statistic across the four models.

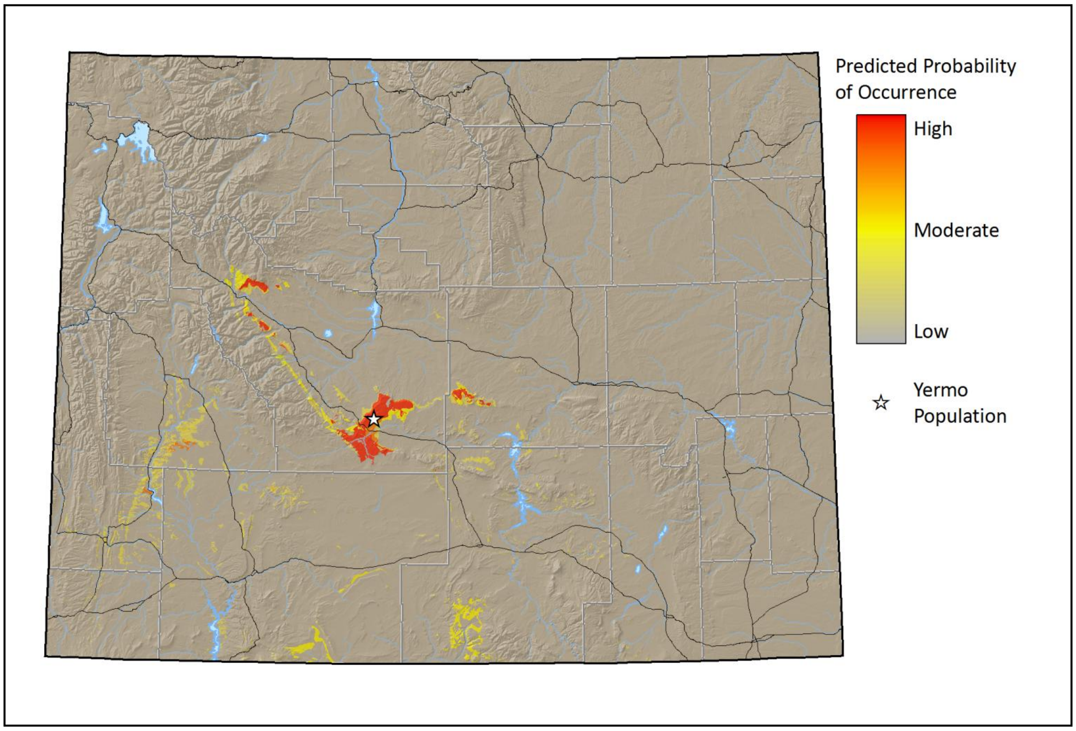
Model	Threshold	AUC	Overall Accuracy	Sensitivity	Specificity	True Skill Statistic	Kappa
Species Intersection	6	0.7368	44.4%	**100.0%**	34.2%	34.2%	13.9%
State	0.114469	0.4248	51.1%	71.4%	47.4%	18.8%	9.2%
Regional	0.104701	0.7030	77.8%	**100.0%**	73.7%	73.7%	46.6%
Hybrid	0.036968	**0.8008**	**84.4%**	**100.0%**	**81.6%**	**81.6%**	**57.9%**

Results for each model are presented in the following pages, and the key variables in the Regional Model are detailed as they reflect on predicting *Yermo* distribution.

Species Intersection Model
The species intersection model identifies potential habitat for *Yermo* primarily along Beaver Rim from an area west of Crooks Mountain and running north and then eastward into Rattlesnake Hills (Figure 5). Smaller areas of potential habitat are identified on the southern flanks of the Absaroka Range and the northern portion of the Wind River Range, and in the Green River Basin.

ROC analysis based on the 2010 survey data identified the optimal threshold (i.e., that which maximized the sum of sensitivity and specificity) as 6 (Appendix B). When this threshold was applied, the model accurately predicted the new population of *Yermo* found during the 2010 survey. However, the model also predicted many areas that were found not to contain *Yermo* during the 2010 survey and in prior surveys, having the lowest accuracy of models tested (Table 1). It seems noteworthy that both *Cirsium pulcherrimum* var. *aridum* and *Phlox pungens* were found growing with *Yermo* in the new population, representing extensions of previously documented populations nearby.

Figure 5. Species intersection model of *Yermo* distribution, Wyoming.



Statewide Maxent Model

Eleven variables were selected for use in the final statewide model (Table 2) using the jackknife methods described above. These variables reflect likely preferences by the species for predictors that vary at both coarse (i.e., climate, landscape structure) and fine scales (i.e., soil characteristics, vegetative cover). The ROC graph and *Yermo* response to each parameter in the statewide model is presented in Appendix B. The statewide model predicted occurrence of *Yermo* in several basin and foothill areas within the state (Figure 6). However, the statewide Maxent model was the least useful model by most measures (Table 1). This model had the lowest sensitivity value across all models, as it failed to predict two of the newly discovered subpopulations using the chosen threshold. This lack of sensitivity likely reflects the difficulty in building a statewide model that can identify the fine-scale habitat conditions that influence the distribution of a narrowly-distributed species.

Figure 6. Final statewide Maxent model of *Yermo* distribution, Wyoming.

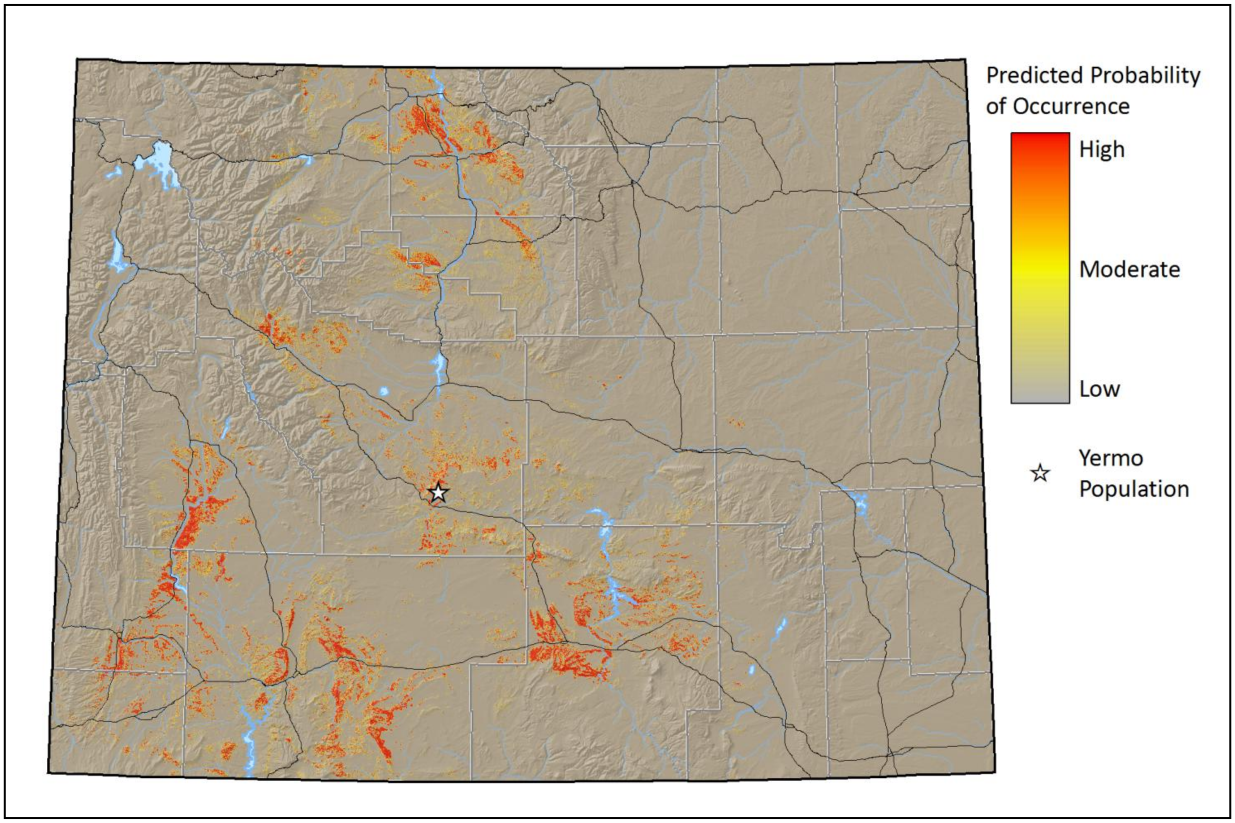


Table 2. Variable contribution for the final 11-variable statewide model of distribution of *Yermo* using the Maximum Entropy algorithm

Variable	Percent contribution
Precipitation of the Warmest Quarter	19.7
Shrub Cover	15.6
8-Category Aspect	15.5
Potential for Rock Outcrop	13.7
Soil Texture	11.1
Contagion Index	9.6
Driest Quarter Mean Temperature	5.6
Depth to Shallowest Restrictive Layer	4.0
Annual Total Radiation	2.1
Bare Ground Index	1.7

Regional Model

Eight variables were used in Maxent to build the final, regional distribution model (Table 3). Compared to the statewide model, the variables in the regional model reflect more emphasis on finer-scale environmental features and attributes, including rock outcrops, aspect, and soil characteristics. These environmental attributes as indicators of *Yermo* habitat conditions and requirements are presented in the discussion section. The ROC graph and *Yermo* response to each parameter in the regional model are presented in Appendix B.

Table 3. Variable contribution for the final 8-variable regional model of distribution of *Yermo* using the Maximum Entropy algorithm

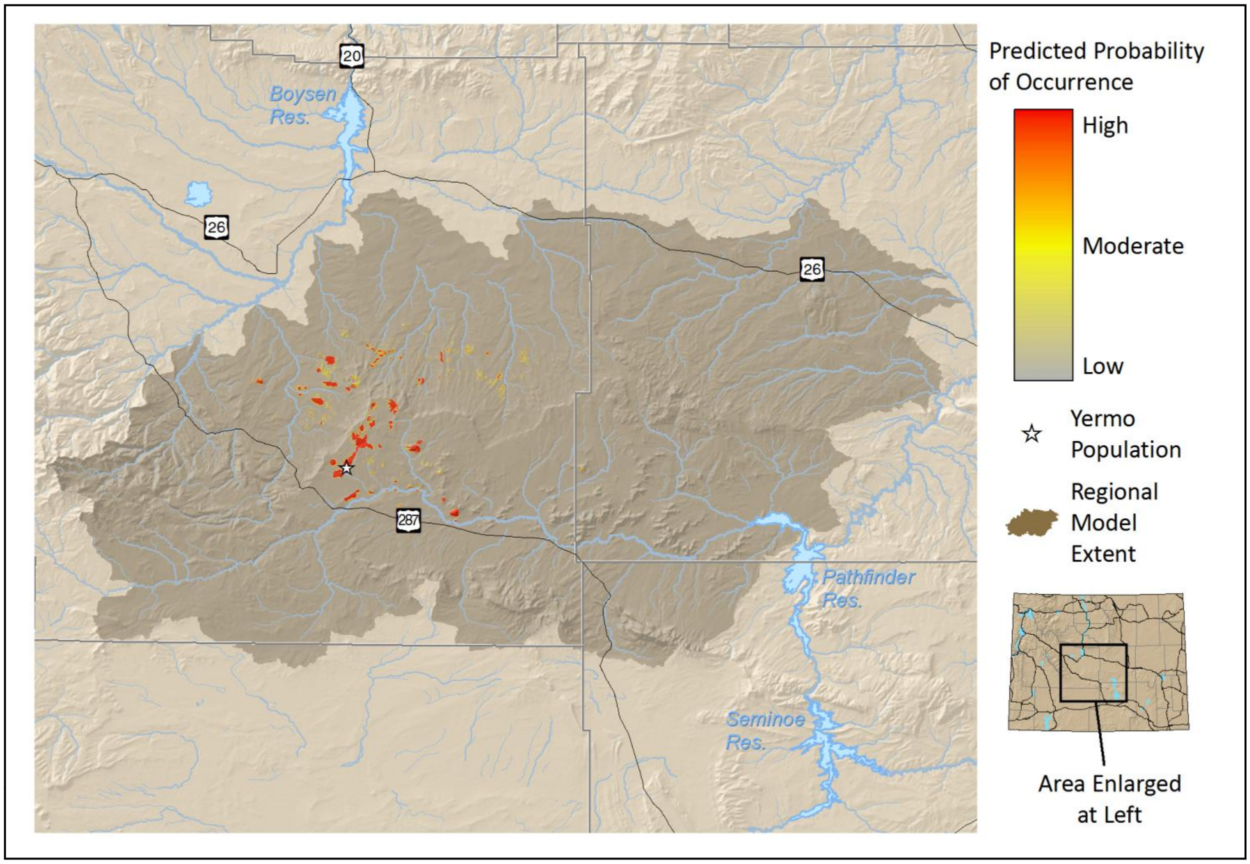
Variable	Percent contribution
Potential for Rock Outcrop	16.1
8-Category Aspect	15.9
Soil Texture	14.9
Depth to Shallowest Restrictive Layer	12.1
Annual Total Radiation	11.2
Radiation of the Lightest Month	11.0
Wettest Quarter Mean Temperature	10.6
Annual Relative Humidity Range	8.3

The eight variables and correlation patterns presented in Appendix B graphs are described below:

- *Potential for Rock Outcrop – Yermo* distribution is centered on locales with short distances to rock outcrops.
- *8-Category Aspect – Yermo* distribution is centered on locales with discrete south aspect, no north aspect, and lesser east or west aspects.
- *Soil Texture – Yermo* distribution is centered on locales with silt texture to the exclusion of coarser or finer textures.
- *Depth to Shallowest Restrictive Layer – Yermo* distribution is centered on locales with soils at the shallow end of the spectrum.
- *Annual Total Radiation – Yermo* distribution is centered on locales with highest annual total radiation.
- *Radiation of the Lightest Month – Yermo* distribution is centered on locales that have the highest radiation in the lightest month.
- *Wettest Quarter Mean Temperature – Yermo* distribution tends to be at the warm end of the spectrum in the wettest quarter.
- *Annual Relative Humidity Range – Yermo* distribution is centered on locales that have the lowest annual relative humidity.

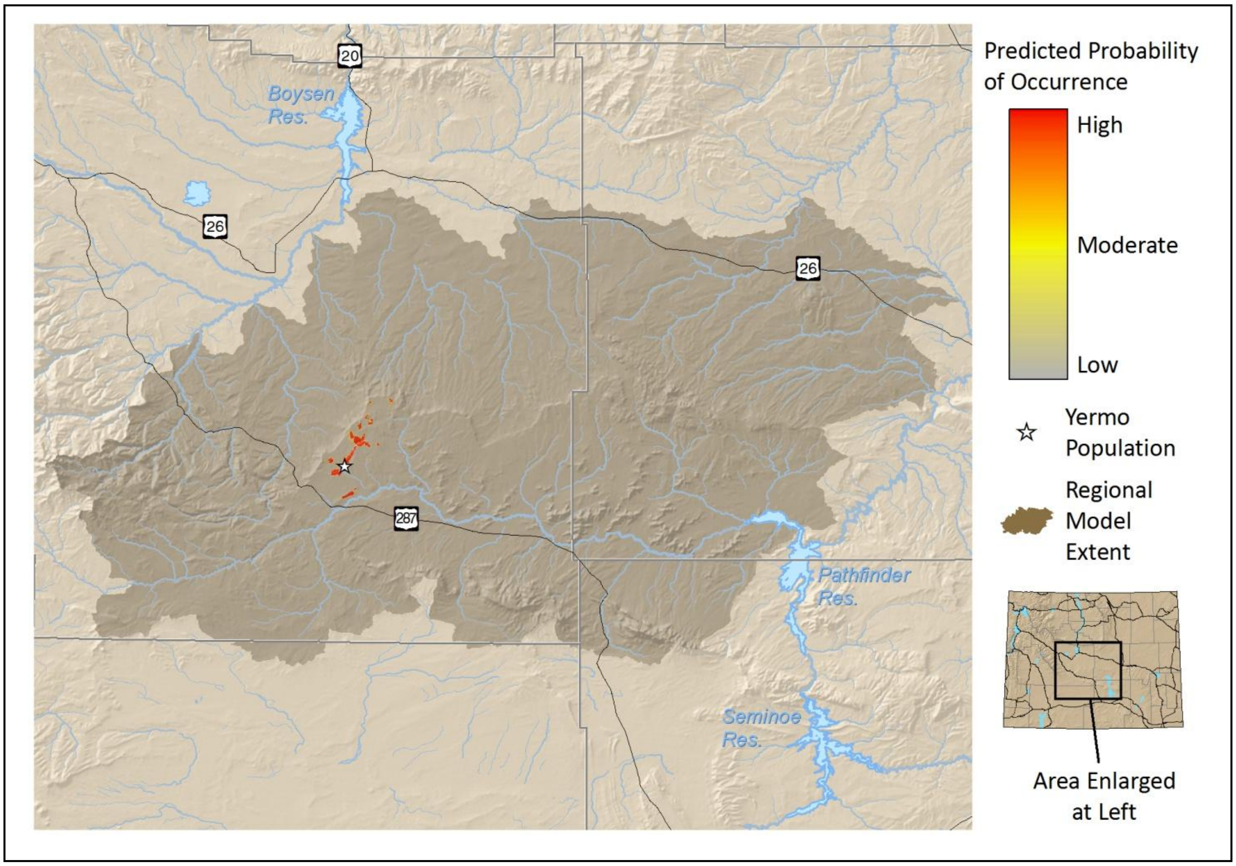
Predictions from this model were necessarily restricted to the chosen region (Figure 7), and accurately predicted a high probability of occurrence at the locations of the newly discovered populations of *Yermo*. In contrast with the statewide model, areas of predicted distribution were much more constrained to apparently suitable locations in the landscape immediately surrounding the previously known and newly discovered populations. This more restricted prediction lead to much higher specificity for the regional model, relative to the species intersection and statewide Maxent models (Table 1).

Figure 7. Final regional Maxent model of *Yermo* distribution, Fremont and Natrona counties, Wyoming.



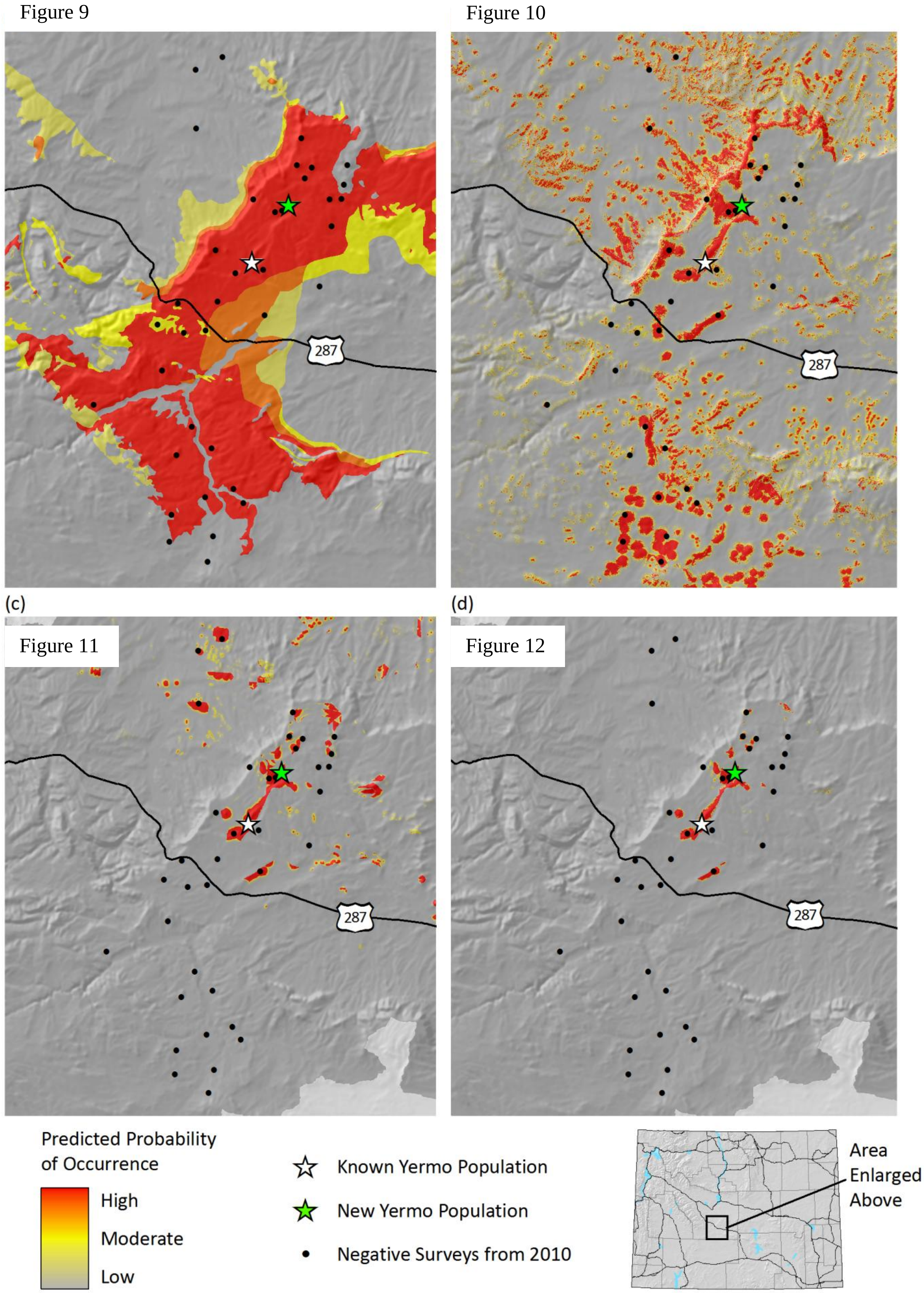
Predictions in this model are constrained to the area used to define the regional model extent, due to the "No Data" values for the regional model outside this area (Figure 8). The model predicts as a likely part of the species' distribution a relatively narrow band along the Beaver Rim. The binary version of the hybrid model has the highest values across all validation statistics (Table 1), with the lowest error rate in predicting as present the fewest number of the negative survey locations from the 2010 survey. The ROC graph and *Yermo* response to each parameter in the regional model is presented in Appendix B.

Figure 8. Final hybrid model of *Yermo* distribution, Fremont County, Wyoming.



Each of the four model outputs is shown with an overlay of the GPS points collected at sites where *Yermo* was surveyed but not found in 2010. They are presented as Figures 9-12 on the next page.

Models of *Yermo* habitat compared with 2010 surveys: Figure 9. Species intersection model; Figure 10. Statewide model; Figure 11. Regional model, and Figure 12. Hybrid model



Discussion

The development of predictive distribution models for species with few known occurrences, limited distributions, or highly specialized habitat requirements poses special challenges. As a consequence, relatively few predictive distribution models are available for Wyoming plant species of concern, and even fewer of these plant distribution models have undergone rigorous field validation. The modeling work presented here and validated using field surveys suggests a number of possible techniques for producing useful models based on limited data. These techniques include sub-sampling of occurrences, applying new modeling algorithms, and combining the predictions from multiple modeling methods. The success of the models in correctly predicting the new population of *Yermo*, particularly that of the hybrid model, indicates that modeling provides a useful tool for locating new species occurrences, even when data for the species and for environmental data are limited.

While predictive distribution models may be used alone to guide surveys, integrating modeling results with ancillary data such as aerial photography and previous survey data can dramatically improve the effectiveness of such field surveys. This is particularly true for narrowly-distributed species such as *Yermo* that are associated with distinct landscape features that are readily apparent on aerial photography but not easily mapped at a statewide scale in environmental predictor layers. GIS geology themes were not used to focus on Miocene sedimentary formations, which might have further reduced the number of unsuitable polygons. In any case, survey targets were honed from broad blocks to discrete areas a hectare or less using photointerpretation to narrow the survey focus. Improved predictor data, such as county-level soil data, may reduce the need for photointerpretation work in guiding surveys, but all models are at best a working hypothesis for the distribution of a species, and should be treated as such.

The hybrid model described here is submitted as a final product in GIS format, and will replace the Fertig and Thurston (2003) model as the posted WYNDD predictive distribution model for *Yermo*. We expect to complete the field testing of the hybrid model and the Fertig and Thurston (2003) model in the 2011 field season.

Maxent is a presence-only modeling algorithm; as such, it was not possible to integrate negative survey locations for *Yermo* in model-building. Presence-absence algorithms, such as Random Forest (Cutler et al. 2007), could take advantage of the negative data from prior surveys. However, given the extensive survey efforts that have been conducted for the species around the two known populations, we believe it is unlikely that additional modeling efforts would identify significant new areas for survey at this time. As with all species of concern in Wyoming, WYNDD will continue to collect and review new data for *Yermo* and consider revising models if we believe it could provide a substantial improvement in knowledge of the species' distribution.

CHAPTER 3. SURVEYS

Background

Surveys for *Yermo* culminated the photointerpretation and potential distribution model work. The monitoring grid outline created by Scott and Scott (2009) at the original Yermo population is presented as part of Appendix A.

Methods

Targets for *Yermo* surveys were digitized as polygons, determined by photointerpretation with or without potential distribution models. Each polygon target had a unique number, and was printed out in the set of 20 quarter-quad printouts carried into the field.

New surveys for *Yermo* were conducted on foot by two botanists during the period when the bright yellow involucres of *Yermo* were conspicuous, in bud through early fruit (22 June – 16 July 2011). Forty-three polygons of potential habitat were surveyed (including three that were added in the course of fieldwork; Figure 3; Appendix A). The information collected from site surveys are highlighted on summary sheets, characterizing soils, topography and vegetation as they compare with known *Yermo* habitat (Appendix C), and documenting any other species of concern (Heidel 2007). Datapoints were taken with a Geographic Positioning System (GPS) unit in each survey polygon to corroborate locations and provide negative data to run models. Survey information for all new rare plant records were collected on the WYNDD sensitive plant survey form for entry in the WYNDD database, and new occurrences of target species were vouchered and photographed.

The rest of the 2010 survey routes where *Yermo* was not found were digitized and added as a fourth theme to that of all prior surveys. These files serve as a GIS-based negative survey reference and are submitted as additional products that accompanying the report.

Results

A new *Yermo* population was located on 23 June in an area targeted for survey. It lies in the same township as the original population. It was in a digitized polygon target identified as having high suitability by all three models and by photointerpretation, together or alone. It was located along one of several escarpments that had been surveyed for many miles, with exception of a gap of about 2 km (1.6 mi).

Closer survey was conducted on 25 June to document six more discrete subpopulations or locales making up the population (Appendix C). They are separated by distances over 10 m. Photographs were taken at each subpopulation, and the range of habitats are represented schematically (Appendix C). A U.S. Fish & Wildlife Service collecting permit amendment was issued the next month in order to collect a voucher specimen representing the new population (*Heidel 3441*). Duplicate specimens are deposited at Rocky Mountain Herbarium and University of California - Berkley. The following survey results at the second population are presented with direct comparison to attributes at the first population. They also provide context for modeling work and habitat documentation.

The seven subpopulations of the new *Yermo* population were conservatively tallied as having at least 400 plants, total. There are fundamental questions about delimiting individual plants at the new population because the spatial pattern of *Yermo* stems relative to one another is much more complex in the second population than the first. The second population is on sloping terrain and has areas of higher density. The conventions that have been used in prior census (Scott and Scott 2009) are to treat all shoots that have overlapping leaf cover at the time of monitoring (August) as one individual. We did not make a late-summer visit to census the population using this standard but conveyed the location information to a separate research team beginning a *Yermo* demographic monitoring study. By comparison with this preliminary result, the population size at the original population has ranged from 9,294-11,813 plants (Scott and Scott 2009).

The new *Yermo* population is a narrow band along escarpment slopes rather than in flats like the original population. GPS points were taken to delimit the population segments. The endpoints were used to map two subpopulation polygons and the rest are represented as points. Using these preliminary measurements, the new population was mapped as occupying less than 0.4 ha of habitat. By comparison, the population extent at the original population is mapped in the Scott and Scott (2009) grid system as occupying 4.4 ha of habitat.

The occupied habitat at the new population is described as: "Upper to lower escarpment slopes, generally south-facing, mostly at ecotone between cushion plant rim and sagebrush grassland toeslope communities on gravelly silt loam derived from White River Formation. Vegetation cover has 5-20% bunchgrasses, including bluebunch wheatgrass and junegrass, accompanied by diverse forbs" (Heidel and Handley 2010).

By comparison, the occupied habitat at the first population is described as: "Deflation hollows, low rims, and rocky washes in barren outcrops of whitish-ashy sandstone at the base of an escarpment with Split Rock and White River Formations. Vegetation cover low (less than 10%), consisting mostly of cushion plants and scattered clumps of Indian ricegrass (*Achnatherum hymenoides*). Thus, the settings of the two populations differ in at least their topographic positions (mid-slope vs. base) and vegetation structures (bunchgrass community vs. barren cushion plant community)" (Fertig 1994). Photographs were taken to represent the typical and atypical habitat in both populations (Appendix C).

The discovery of a second *Yermo* population prompted resurvey of the miles between the two populations. This was the only case in which 2010 surveys repeated previous surveys. *Yermo* was not found during this resurvey.

Incidental to *Yermo* surveys, new populations or subpopulations were found for Cedar Rim thistle (*Cirsium pulcherrimum* var. *aridum*), Beaver Rim phlox (*Phlox pungens*), and Devils Gate twinpod (*Physaria eburniflora*). The quarter-quad example in Appendix A shows three polygon survey targets, two of which had new Cedar Rim thistle populations, and the third barren area proved to be a white-tailed prairie dog colony. New populations were also documented for species in unrelated habitats incidental to surveys, including red poverty-weed (*Monolepis pusilla*) and dwarf woolly-heads (*Psilocarphus brevissimus*). Vouchers were collected and the survey information added to the central WYNDD database.

No signs of land use disturbance were noted in the new *Yermo* population, although an old abandoned road ran between subpopulations, mining claims were noted, and there was some burrowing activity in the area. The nearest roads and pipelines do not appear to have any affect.

Incidental Information Collected

Other observations and photographs were collected incidental to survey. They represent images or information on *Yermo* seeds, seedlings, potential pollinators, and a mortality phenomenon. They are reproduced as a set in Appendix D. Seeds retain the pappus and mature in the latter half of summer, when they can disperse by wind. At the same time that seeds were beginning to mature in early August, a few *Yermo* plants had turned chlorotic. The chlorotic condition appeared to be a cause of mortality, though it had apparently developed after flowering, so that reproduction was not affected. Seedlings were observed just before and during flowering time. Ant visitors were frequent on flowering plants and were the only visitors noted early in the flowering period under low light conditions early and late in the day. The only insects observed feeding on flowers was the nectar-feeding butterfly, small wood nymph (*Cercyonis oetus*), and ants. The butterfly was observed at midday and was common in the *Yermo*1 population, readily visible at a distance because of the red on the dorsal wing surface. Individuals were followed as they flew repeatedly between *Yermo* plants. It appeared as though they visited each flower in the flowerhead before traveling to the next plant. One butterfly individual was caught and photographed using a Q-Color 5 Olympus microscope mount. Determination was made by Cliff Ferris (University of Wyoming) who characterized the species as common in the state. The *Cercyonis oetus* adults feed on flower nectar of yellow composites (Opler et al. 2011). Females deposit eggs singly on host plants (unknown grasses), and first-stage caterpillars hibernate unfed until the following spring. The ants that were observed feeding on *Yermo* flowers were seen in early mornings and early evenings, apparently feeding on nectar. They were not collected or identified.

Discussion

The narrow *Yermo* distribution made it especially suitable to pursue thorough survey. The best predictive tools are only as meaningful as they are used and careful searches are carried out. They have limited utility without fieldwork.

We started this project hypothesizing that *Yermo* has narrow ecological amplitude. There is no evidence especially after discovery of the second population to support the hypothesis. Evidence, therefore, supports the hypothesis that *Yermo* has wide ecological amplitude.

Wind direction and velocity were measured by Scott and Scott (2009) in occupied *Yermo* habitat. They deduced that the site of the original *Yermo* population is sheltered, with a 10 mph or less daily average velocity in summer, and an overall southerly wind direction between July-September when seeds ripen. They charted wind velocity and direction "…to project a downwind plume which would be the most likely path of seed dissemination." Their projection was confirmed in 2010 and winds blew directly between the two populations on one of the 2010 surveys conducted at the new population. Three characteristics of the second population are consistent with it being an outlier of the first population. First, it lies directly downwind at the first topographic interception and same geological formation from the first population. Second, it is over a magnitude smaller in the total number of plants and aerial extent as the first population. Third, plants in the second population are separated from one another by habitat that closely resembles the occupied habitat. The seven subpopulations are distributed as though they were seven separate colonization events along a slope that has much similar, unoccupied habitat.

CHAPTER 4. ECOLOGICAL REQUIREMENTS

Background

Yermo is one of the most geographically restricted vascular plant species in Wyoming. The digitized grid of occupied *Yermo* habitat at the original population totals 4.4 ha (10.9 ac). Many species with highly restricted distribution are thought to have narrow habitat requirements reflecting environmental conditions that are also very restricted. Highly restricted vascular plants may have evolved recently or long ago.

There are several hypotheses on the origin of *Yermo* (Dorn 1991, Scott and Scott 2009). It was beyond the scope of this study to evaluate origin, but comparative habitat analysis was developed to determine if there are any characteristics peculiar to *Yermo* habitat not found in surrounding vegetated and unvegetated settings. The ecological requirements determine the degree of habitat specificity, which in turn may temper the options for this species' management and recovery.

Methods

Soils

Seven of the twelve original soil samples collected by Richard and Beverly Scott and Kent Houston in 2000 and 2001 were tested in detail by the NSSC Soil Survey Laboratory and results were incorporated into a national soils characterization database (Soil Survey Staff 2010). For each sample, particle size fraction, and profile depth interval, the following additional tests were run: percent water at the classical wilting point (% H_20 at 1500 kpa), total organic carbon, total nitrogen, total sulfur, extractable bases (Ca, Mg, Na, K), sum of bases and acidity, cation exchange capacity, electrical conductivity, exchangeable sodium, pH in $CaCl_2$, pH in water, and extractable phosphorus (Burt 2011). Raw data from these tests are posted in the national soils characterization database homepage (Soil Survey Staff 2010) and were analyzed as part of the current study using a student T-test. Five main differences between the *Yermo* habitat soils and other soils were identified as significantly ($p<0.05$) different between sites occupied by *Yermo* and those where *Yermo* was absent (Williams 2010; Appendix G):

1. *Yermo* occupied soils had higher silt content (53.5 vs. 32.6 %)
2. Lower carbon content (0.4 vs. 1.0 %)
3. Lower nitrogen content (0.04 vs. 0.1 %)
4. Lower sulfur content (0.01 vs. 0.02 %)
5. Higher potassium content (765 vs. 508 mg/kg)

In 2010, additional soil sampling was conducted by Richard and Beverly Scott. Samples were collected from a total of 26 sites between 20 June – 8 July, from the original *Yermo* population (n=5, referred to as *Yermo*1 in the following figures), from surrounding sagebrush landscapes (n=10, referred to as "Steppe"), and from soils at Dishpan Butte, a site superficially similar to the occupied *Yermo* site (n=6, referred to as "potential" in the figures). Soil was sampled at 0-15 and 15-30 cm depths at every site except two sites with shallow soils that did not have subsurface soil (one at the original *Yermo* site and one of the Dishpan Butte sites). Discovery of a new *Yermo* population expanded the soil sampling (n=5, called *Yermo* 2 in the figures). One of the 10 sagebrush steppe sample sites (#14414) had parent material that was atypical of the area at 0-15 and 15-30 cm intervals (R. Belden pers. commun.). It was eliminated in the statistical analysis. Therefore, 25 sites, all but two with surface (0-15 cm) and subsurface (15- 30 cm) samples, were represented for a total of 48 samples. Each sample at each site and at each depth interval was mixed and divided into three sub-samples. The first set was submitted to the University of Wyoming (UW) Soils Testing Lab for a battery of tests using NSSC compatible methodology. Eighteen tests were run at the University of Wyoming Soils Testing Lab (listed below), in addition to Munsell wet/dry soil color. For each set of values, the standard deviation and upper and lower 95% confidence intervals were calculated.

Cation exchange capacity (cmoles+ /kg)
Calcium carbonate equivalent ($CaCO_3$)
Sand content (%; pipette analysis
Silt content (%); pipette analysis
Clay content (%); pipette analysis
pH (saturation extract)
Electrical conductivity (dS/m)
Organic matter (% loss on ignition)
Total carbon (%)
Total nitrogen (%)
Available potassium (mg/kg)
Available phosphorus (PO_4-P; mg/kg; Olsen Method))
Coarse fragments content (%)
Soluble calcium (Ca; meq/l)
Soluble magnesium (Mg; meq/l)
Soluble sodium (Na; meq/l)
Sodium absorption ratio
Selenium (PO_4 extractable)
Munsell wet/dry soil color

The second set of samples was submitted to the BLM National Mineralogy Laboratory (Worland, WY) for mineralogy analysis, in order to evaluate the origin of parent material and identify special properties of such material. The third set was submitted to the UW Botany Department – to Brent Ewers Laboratory in order to determine water release rates.

Vegetation

Additional vegetation sampling was initiated in 2010 when a second *Yermo* population was discovered, using the same relevé method (Benninghoff 1966) as employed by Scott and Scott (2009). The square-meter plots were placed throughout occupied habitat, and spaced over a meter apart to reduce auto-correlation. They were non-randomly placed to always include a *Yermo* plant, as had been done in prior sampling. They were also deliberately placed to sample within each of the seven scattered subpopulations, ranging in length from 3 m to approximately 50 m. At each subpopulation, 1-3 plots were taken depending on length of the subpopulation (n=18). All species present were recorded and placed into cover class categories. Sociability values were also recorded for all species.

All species were identified and recorded following the nomenclatural treatment in Dorn (2001). The detailed vascular flora checklist for the area (Appendix 4, in Scott and Scott 2009) was referenced, and a data table was constructed for analysis using a nonparametric multidimensional scaling (NMS) in PC-ORD (McCune and Grace 2002). Presence/absence data for *Yermo* was excluded from analysis because it was a factor in plot placement. The combined Scott and Scott data totaled 62 plots containing 54 species. The combined 2010 data collected at the second *Yermo* population totaled 18 plots containing 52 species. The total was 80 plots and 82 species (including *Yermo*).

In addition, two pilot studies were conducted to provide context for understanding and interpreting habitat requirements of *Yermo*, while also understanding its adaptations relative to other species in the landscape.

1. Symbiosis - Pilot work on *Yermo* mycorrhizal symbiosis was conducted under the leadership of Steve Williams (Department of Renewable Resources, University of Wyoming). This separate study is presented in Appendix E, and contributes to characterization of *Yermo* habitat requirements and rhizosphere ecology.

2. Ecophysiology Adaptations - Pilot work on *Yermo* ecophysiological behavior was undertaken under the leadership of Brent Ewers (Department of Botany, University of Wyoming). This separate study is presented in Appendix F, and contributes to characterization of *Yermo* adaptations to its habitat.

Results

The original purpose of this effort was to distinguish habitat characteristics in occupied (*Yermo*1) habitat with characteristics in prevailing sagebrush sites, and with unoccupied "potential habitat." Discovery of a second *Yermo* population added another dataset to the analysis of soils and vegetation, presented side-by-side in the results that follow.

Soils

Results for all parameters addressed in two prior soils analyses (Scott and Scott 2009, Williams personal communication) are presented below with a brief summary and confidence interval graphs. A complete record of soils results are presented in Appendix G.

*Yermo*1 (original population) soil samples have high silt levels compared to all other samples. But *Yermo*2 (second population) soil samples have lower silt levels compared to all other samples. High silt content among *Yermo*1was previously reported by Scott and Scott (2009) and determined to have statistical significance in NSSC data analysis (Williams 2010; Appendix G). The discovery of the second *Yermo* population in 2010 and subsequent soil analysis obviates the finding that silt level is a necessary characteristic of *Yermo* habitat.

Among the remaining soil tests, results for available potassium (mg/kg) were highly significantly ($r=0.398$, $p<0.01$) correlated to silt content of all soils (Figures 13 and 14). *Yermo*1 soil samples have high available potassium compared to all other samples, with *Yermo*1 samples differing from *Yermo*2 samples more than they differ other soils elsewhere in the landscape (Figure 14). That silt content and available potassium have such strongly correlated tendency suggests that parent material mineralogy and particle size are interrelated. Further, both physical and chemical soil properties differ sharply between *Yermo*1 and *Yermo*2 samples. This suggests that the soils of the two populations may have different parent material. However, topographic differences, differences in microclimate and perhaps differences in other organisms, may also play into the differences between the soils at sites of these two populations.

*Yermo*1 soils were previously reported to be slightly more alkaline than non-*Yermo* soils (Scott and Scott 2009, Williams 2010). By contrast, *Yermo*1 soils sampled in 2010 were less alkaline than non-*Yermo* "potential" soils and about the same pH as "Steppe" non-*Yermo* soils (Figure 15). *Yermo*2 has pH values that resemble soils in a similarly bare, sloping setting of lie the "potential" non-*Yermo* habitat. The pH differences often reflect differences in $CaCO_3$ content (Figure 16) as they seem to here.

Figure 13. Soil silt content (%) in *Yermo* and non-*Yermo* habitats

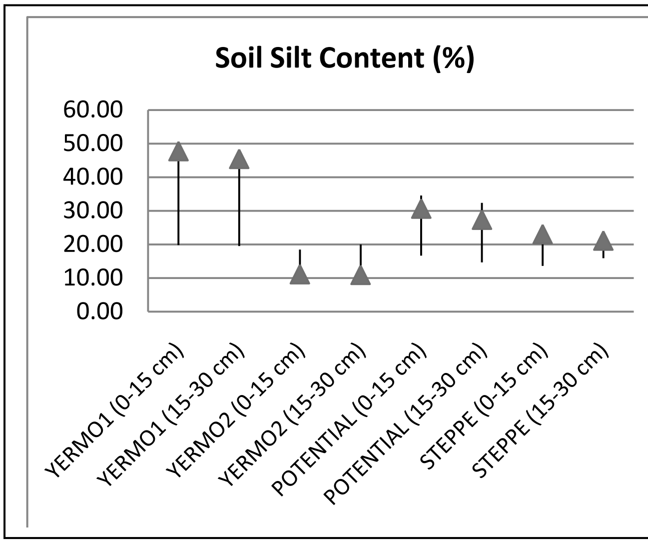


Figure 14. Soil available potassium (mg/kg) in *Yermo* and non-*Yermo* habitats

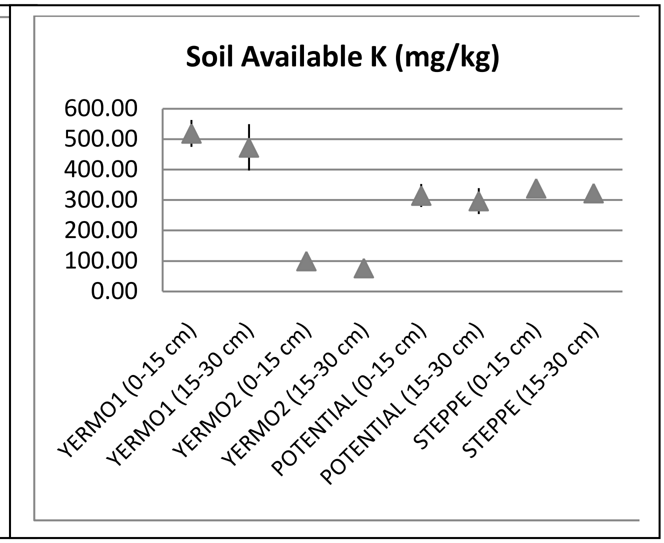


Figure 15. Soil pH in *Yermo* and non-*Yermo* habitats

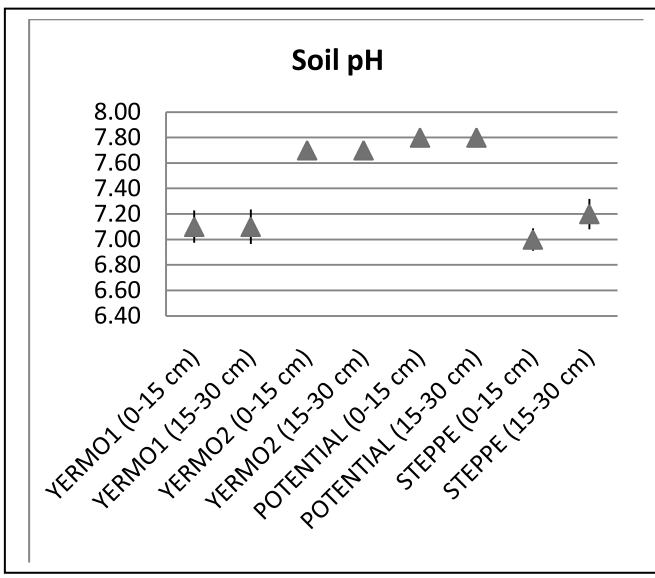
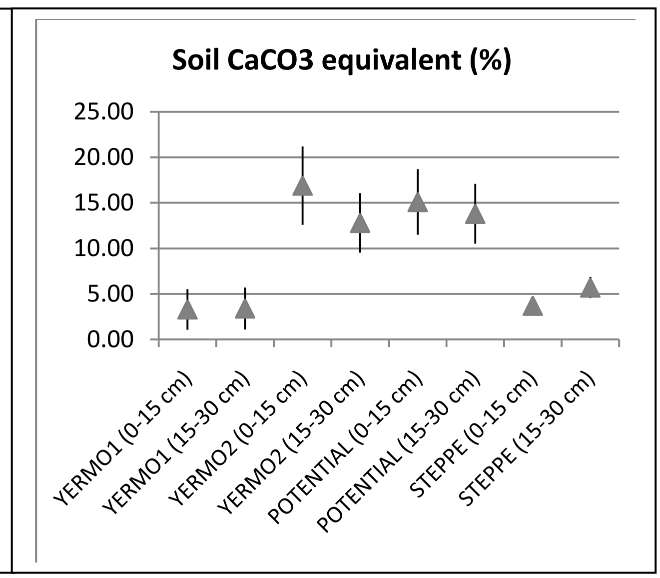


Figure 16. Soil calcium bicarbonate equivalent (%) in *Yermo* and non-*Yermo* habitats



*Yermo*1 soils were reported as having lower total carbon content than non-*Yermo* soils (Williams 2010). This same pattern is reflected in the current analysis, with exception that *Yermo*2 soils have higher total carbon content than any other soils sampled in the landscape (Figure 17). *Yermo*1 soils were also reported as having lower nitrogen content than non-*Yermo* soils. This is true for *Yermo*1 soils but not *Yermo*2 soils (Figure 18). The sagebrush steppe soils have higher nitrogen content than all others in the landscape.

Figure 17. Soil total carbon (%) in *Yermo* and non-*Yermo* habitats

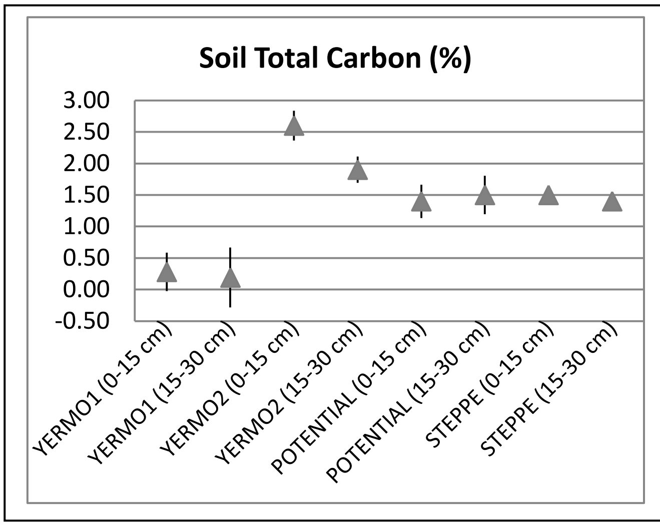
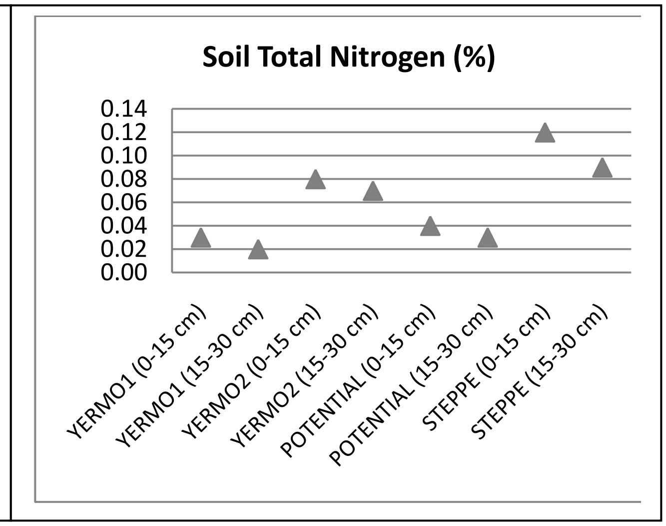


Figure 18. Soil total nitrogen (%) in *Yermo* and non-*Yermo* habitats



*Yermo*1 soil samples were previously (2010) reported as having lower organic matter content than the combined non-*Yermo* habitats. The current analysis supports this, but they are not nearly as low as *Yermo*2 soils (Figure 19). All soils in the landscape are low in available PO_4-P, except for the 0-15 cm sample in sagebrush steppe (Figure 20).

Figure 19. Soil organic matter (LOI) in *Yermo* and non-*Yermo* habitats

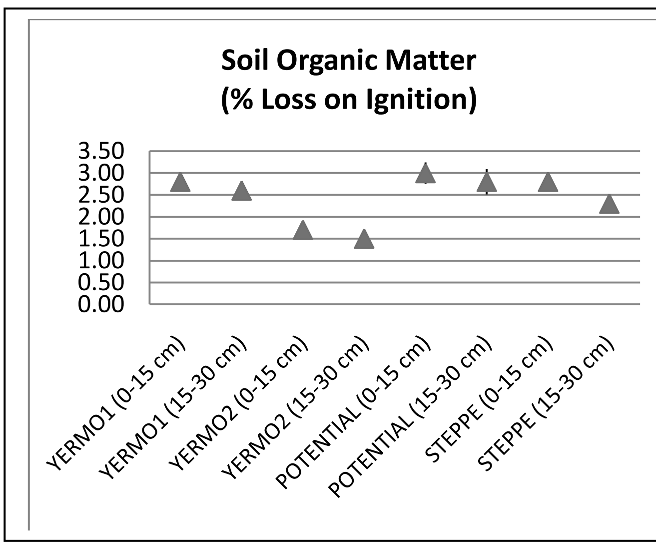
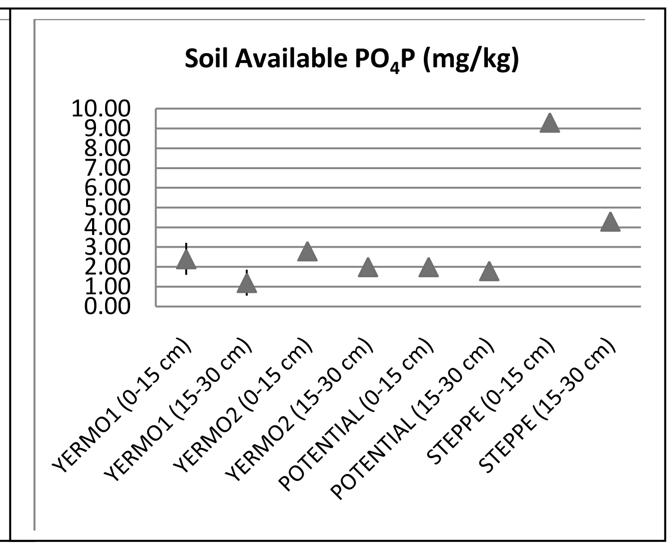


Figure 20. Soil available PO_4P (mg/kg) in *Yermo* and non-*Yermo* habitats



Sodium levels are fairly low in all samples. The sodium absorption ratios bear out that sodium is not an important issue in this landscape at least as it may impact soil structure and hydraulic conductivity.

Figure 21. Soil soluble sodium (meq/l) in *Yermo* and non-*Yermo* habitats

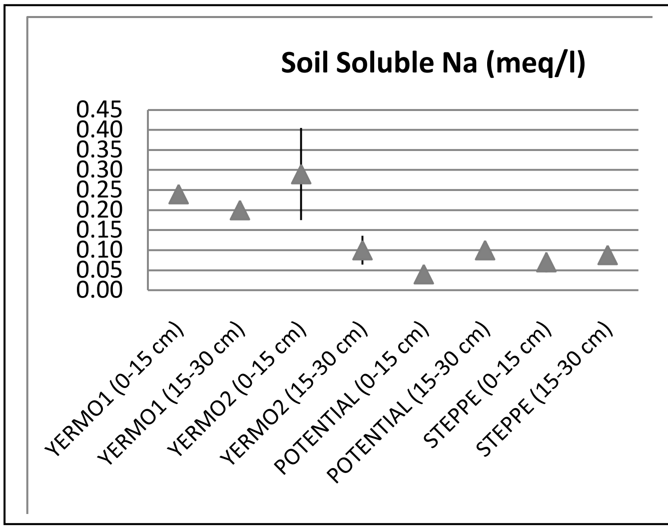
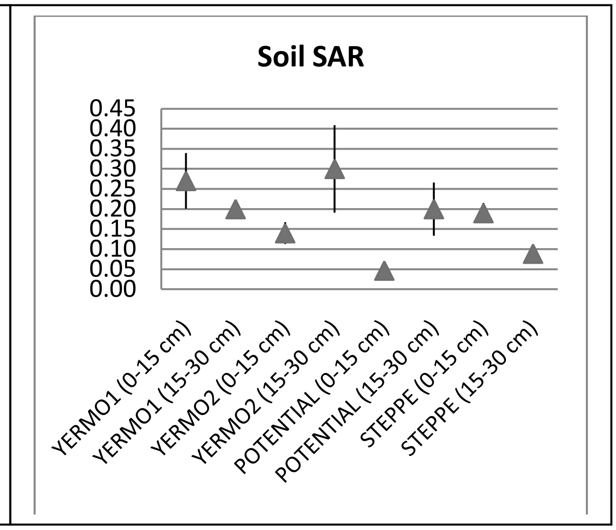


Figure 22. Soil SAR in *Yermo* and non-*Yermo* habitats



Color characterizations were the same as reported by Scott and Scott (2009) in which color of *Yermo*1 soils were consistently light compared to non-*Yermo* soils. *Yermo*1 has significant differences from both steppe and potential habitat with regards to silt content, potassium, pH, total carbon, and total nitrogen; adding significance to preliminary results using the NSSC data (Williams 2010). However, *Yermo*1 does not appear to have significant differences from both steppe and potential habitat with regards to organic matter, as hypothesized earlier (Scott and Scott 2009). On this basis alone, *Yermo*1 soils stand out as different in this landscape from both steppe and potential habitat. However, in all but available PO_4-P, *Yermo*1 soils differ considerably from *Yermo*2 soils more than they do from one or both of the Steppe and the Potential soils. *Yermo*2 soils results refute the assumption of uniqueness of soils in occupied *Yermo* habitat. Complete soils results are presented in Appendix G.

Only one soil variable was found to be similar between *Yermo*1 and *Yermo*2 habitat, the soluble sodium levels (meq/l). Though significantly higher than the rest of the landscape, it seems doubtful that sodium levels define niche space because salt accumulations are not visible at the surface and obligate halophyte species are absent from vegetation sampling data. It is unlikely to be a unifying commonality between habitat conditions of the two *Yermo* populations unless there are trace metals or metalloids associated with elevated soluble sodium levels.

The analysis done in 2010 on the 2002 soil sample data (Williams 2010) suggested that *Yermo* distribution was significantly controlled by soil characteristics. Indeed, the hypothesis driving the soils work in 2010 was that soil characteristics controlled the distribution of *Yermo*. The null hypothesis, that soil characteristics do not control *Yermo* distribution, is a key point in this investigation. The discovery of the second *Yermo* population and the subsequent analysis of the associated soils provide strong support for the null hypothesis and rejection of the original hypothesis.

Results from mineralogy tests and water release rate analyses are not available to date.

Vegetation
Nonmetric Multidimensional Scaling (NMS) analysis of presence/absence data in the 80 vegetation plots were run with the full species list (81 species) and then with the most frequent species (44 species) present in six or more of the 80 plots. The complete list of species is presented in Appendix H, along with the species area curve showing the ordination cut-off threshold.

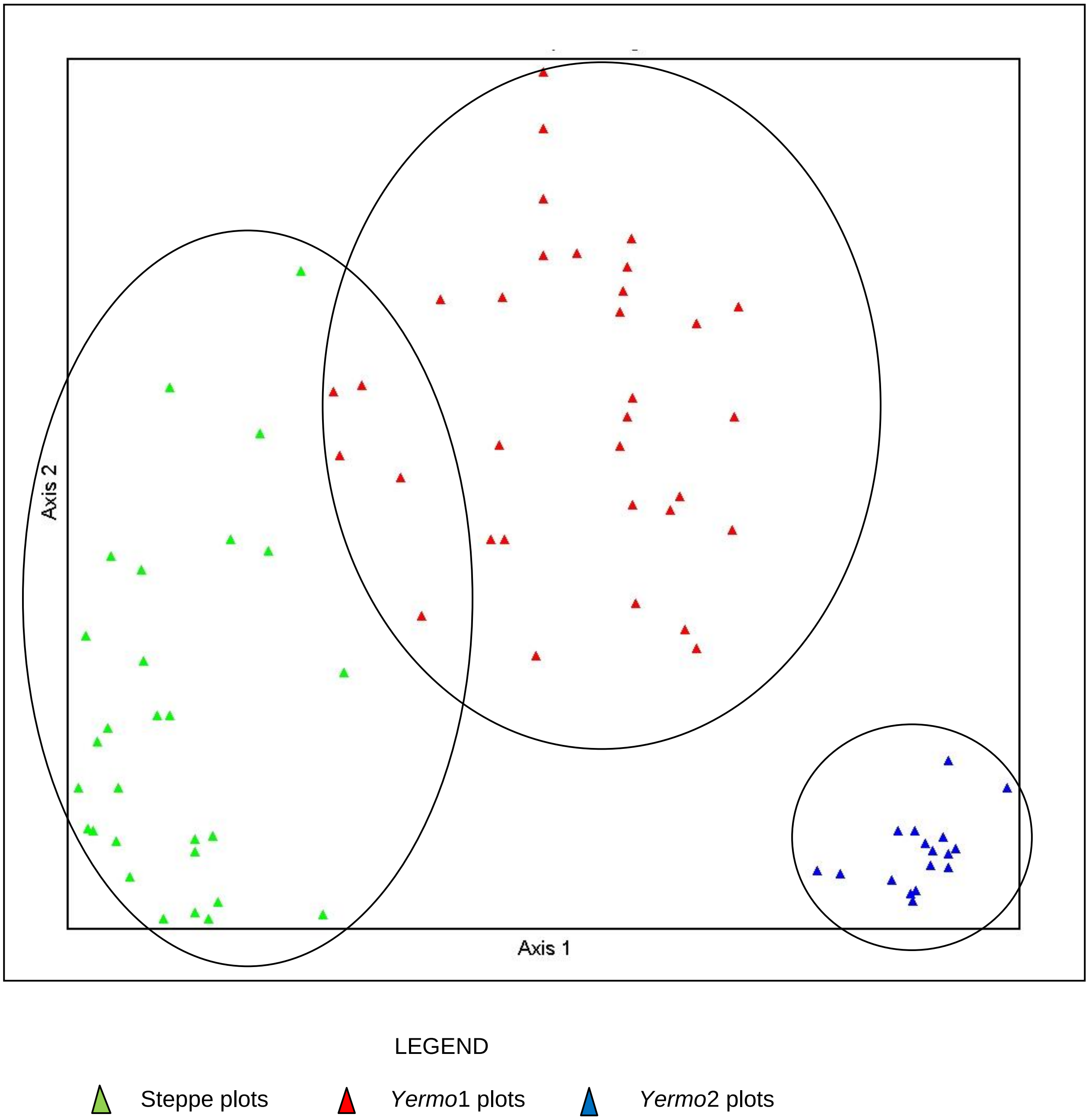
Ordination results as represented schematically in two dimensions show no overlap between *Yermo*1 and *Yermo*2 vegetation composition, and very little between *Yermo* 1 and sagebrush vegetation composition (Figure 23). The ordination produced with the shortened list produced a final solution with three dimensions and a final stress of 14.365, indicating good ordination with low risk of drawing false inferences (McCune and Grace 2002). Final instability was 0.00093 with 500 iterations. The 3 axes accounted for 65.52% of the variation within the dataset; axis 1 accounted for 33.72% of the variation and axis 2 accounted for 21.60% of the variation (Figure 23). Axis 3 (not shown) accounted for 10.20% of the variation.

The number of plots in the *Yermo*2 vegetation was significantly smaller than either of the other vegetation datasets. However, the sampling spanned all seven *Yermo*2subpopulations and their respective settings. The *Yermo*2 plots clustered closely together in ordination hyperspace despite the limited sample size. This is reflected in the fact that there are many species of high frequency shared between *Yermo2* plots, far more than either of the other two vegetation sample sets.

Of the 81 species, only the two sagebrushes are woody, including Wyoming big sagebrush (*Artemisia tridentata* var. *wyomingensis*) in sagebrush steppe, and low sagebrush (*Artemisia arbuscula* var. *arbuscula*) occasional within and generally below *Yermo*2 habitat. Fourteen of the species are graminoids, and 45 are forbs. The forbs include just one exotic species in the sampling data, desert madwort (*Alyssum desertorum*), found in only one plot taken within the *Yermo2* population.

The composite species list was originally composed of 90 species. *Yermo xanthocephalus* was excluded from analysis because plots within *Yermo* populations were deliberately placed to include *Yermo* plants. Whitlowgrass (*Draba* spp.) in the previous sample set was provisionally inferred to correspond with the few-seed whitlowgrass (*D. oligosperma*) found to be common in *Yermo*2 because there were only two species of *Draba* in the Scott and Scott (2009) floristic list, and *D. oligosperma* appears to be most common in the landscape. Milkvetch (*Astragalus* spp.) in the previous sample set may refer to any of several species, but is apt to include the *A. kentrophyta* common in *Yermo*2 and *Yermo*1. Ordination was run keeping them separate. *Arenaria stricta* in the previous sample set was provisionally inferred to correspond with *A. hookeri* (*Eremogone hookeri*). The rest of the possible determination differences between 2010 sampling determinations and prior determinations involved species of low frequency, and they were not used in the final ordination.

Figure 23. Nonmetric Multidimensional Scaling (NMS) ordination of *Yermo* and non-*Yermo* vegetation datasets. Points in ordination space represent individual plots. The point colors and oval shapes identify vegetation dataset categories.



Axis 1 corresponds closely to composition among graminoids and shrubs. Axis 2 corresponds closely to composition of a subset of cushion plant forbs (Table 4). The ordination also suggestions that *Yermo*2 plots are more closely related to one another in vegetation composition hyperspace than *Yermo*1 plots or sagebrush steppe plots.

Table 4. Species of high frequency in vegetation of the three settings (*Yermo*1, *Yermo* 2, Sagebrush steppe). Species that are unique to the particular sample setting, and not found in the other two plot sample sets, are asterisked.

Scientific Name	**Common Name**	***Yermo*1**	***Yermo*2**	**Steppe**
Artemesia tridentata var. *wyomingensis*	Wyoming big sagebrush			X*
Astragalus spp. (probably *A. kentrophyta*)	Spiny milkvetch	X*		
Carex filifolia	Thread-leaved sedge		X	
Commandra umbellata	Bastard toadflax		X	
Cordylanthus ramosus	Bushy bird's-beak			X
Draba oligosperma	Few-seed whitlowgrass		X	
Elymus spicatus	Bluebunch wheatgrass		X	
Elymus trachycaulus	Slender wild rye			X*
Festuca ovina	Sheep fescue			X
Gilia tweedyi	Tweedy's gilia			X*
Ivesia gordonii	Gordon's ivesia	X*		
Koeleria macrantha	Junegrass		X	
Linanthus pungens	Granite prickly-phlox		X	
Linum kingii	King's yellow flax		X*	
Machaeranthera grindelioides	Rayless tansy-aster	X	X	
Minuartia nuttallii	Brittle stitchwort		X	
Packera cana	Silver-woolly groundsel		X*	
Penstemon humilis	Low beardtongue		X*	
Phlox hoodii	Hood's phlox			X
Phlox pungens	Beaver Rim phlox		X*	
Poa secunda	Sandberg's bluegrass		X*	

Of the 81 species present in the three sample sets, 20 have very high frequency within one or more sets (over 50% of plots; Table 1). There are few species having high frequency in *Yermo*1, and they are all forbs that are characterized as having a cushion plant growth form, including spiny milkvetch (*Astragalus kentrophyta*), Gordon's ivesia (*Ivesia gordonii*), and rayless tansy-aster (*Machaeranthera grindelioides*). There are many species having high frequency in *Yermo*2. Two of the several species having high frequency in Steppe include the sagebrush dominant, Wyoming big sagebrush (*Artemisia tridentata* var. *wyomingensis*), and its associated saprophyte, bushy bird's-beak (*Cordylanthus ramosus*).

Of the 81 plant species in the vegetation plots, over half (45) were in one set of plots but not the other two sets. Only one associated forb was frequent in both *Yermo*1 and *Yermo*2 plots, rayless tansy-aster. The two most widely-distributed species shared between all three vegetation sample sets were moss phlox (*Phlox muscoides*) and stemless mock goldenweed (*Stenotus acaulis*), though they were present at less than 50% frequency in each of the sample sets.

Discussion

The new *Yermo* population lies immediately downwind from the original *Yermo* population at a point of topographic interception. If *Yermo* was once widespread, then one would expect that there are likely to be differences in habitat conditions between the two populations, and that they have a distribution pattern independent of dispersal patterns. If *Yermo* remained highly restricted since its origin, then one would expect closely related habitat conditions, and that they have a distribution pattern consistent with dispersal vectors, possibly in a source-sink relationship. The distribution pattern is consistent with *Yermo*2 originating as one or more wind-dispersal events linked to *Yermo*1. However, the habitat conditions contrast significantly in both soils and vegetation, consistent with the idea that *Yermo* may have been more widespread and its distribution contracted. The results are discussed on following pages.

Soils

Yermo soils at the first population are distinct from those of surrounding steppe by at least eight of 17 properties. However, we failed to support the original hypothesis after discovery of a second *Yermo* population with fundamentally different soils attributes. Ten of 17 properties differed between soil conditions at the two *Yermo* populations. It is not appropriate to assume in a battery of tests that each parameter has equal significance so direct comparisons are made below. Any one value or combination of values may be decisive, and correlation does not prove causation although it may be reason to formulate hypotheses.

Potassium levels in *Yermo*1 soils are higher than all other sample sets, and approach that of fertilized agricultural land (Barber 1995). The amount of potassium absorbed by crop plants is often greater than any other mineral (Barber 1995). By contrast, nitrogen levels in *Yermo*1 soils are lower than all other sample sets. Potassium levels typically enhance the assimilation of nitrate into protein (Koch and Mengel 1974). Nitrate is often a limiting nutrient in arid settings. More information is needed about the forms of nitrogen to say it is limiting and whether high potassium in *Yermo*1 soils could be partially compensatory for otherwise nutrient-poor conditions.

The high values in available potassium may possibly reflect high tuff content in the *Yermo*1 soils. In general, the main potassium-bearing minerals in soils are micas, feldspars, and illite in clays (Barber 1995). The latter is ruled out by soil texture. Future mineralogy results may shed light on the parent material.

Another nutrient that is often limiting in most environments including arid environments is phosphorus. The main benefit from mycorrhizas that has been established is the increase in phosphorus uptake enhanced by these symbiotic associations, particularly for plants growing in low-phosphorus soils (Barber 1995). Under these conditions, the presence of mycorrhizas (Appendix E) may ameliorate stress in nutrient uptake, salinity tolerance, and also facilitate water uptake. The water availability in these arid systems often has the greatest impact on all facets of nutrient uptake. Thus, despite comparatively low PO_4 levels in *Yermo*1 soils, the presence of mycorrhizae may compensate in reducing, or ameliorating, the affects of low-phosphate conditions.

We have not provided evidence in support of the habitat specialist theory, but we have narrowed down the range of possible soil conditions in common between the two populations. Of the few characteristics in common, both population sites have relatively high sodium levels at least in the upper horizon, although much lower than typically found in sodic soils. *Yermo* has the succulent leaves and stems typical of halophytes. These populations may have developed in soils that were either salty, saline or both, and changes in drainage and salt type and content have left them as remnants of such edaphology. Soluble sodium levels may also point to associated minerals that have not been measured, both of which are conjecture. They may also point to soil physical properties, including surface characteristics, affecting water absorption at the surface as documented in area exclosures (Madden 2005).

Indeed, the most consistent interpretation for the data at hand is that *Yermo* is not a habitat specialist. For this to be true, both populations would be similarly viable.

Vegetation

Vegetation at the first *Yermo* population is very distinct from that of surrounding steppe vegetation in composition (presence/absence), structure, and abruptness of the transition between. However, we failed to prove the null hypothesis in its original form by discovery of a second *Yermo* population with fundamentally different vegetation compared to the first population. Many of the vegetation conditions at the second *Yermo* population are as different from those at the first population as they are from vegetation in surrounding steppe. Soils and vegetation are related to one another, so vegetation results do not offer independent proof of soils results. They are interdependent and represent all of the differences associated with the grass-dominated vegetation in the *Yermo*2 habitat as compared to the cushion plant-dominated vegetation in the *Yermo*1 habitat or sagebrush steppe vegetation.

Cover values were determined in *Yermo*2 habitat, with totals ranged from 15-45% cover by tallying median species values. These totals are high and do not take into account overlapping cover. They are definitely higher than the vegetation cover in *Yermo*1 habitat, described by Fertig (1995) as much less than 10% cover throughout. Vegetation photographs of the two population settings are presented in Appendix C.

Of the few characteristics shared in common between *Yermo* habitat datasets, both population sites have high frequency of cushion plants, although not the same ones. *Phlox pungens* (Beaver Rim phlox) and *Linanthus pungens* (prickly phlox) grow in occupied habitat of *Yermo*2 but are absent or distant at *Yermo*1.

We note that very different conclusions would be drawn if there were only one *Yermo* population for soil and vegetation analysis. A demographic monitoring study has begun that addresses both populations, and which will provide information on their population growth rates as indication of habitat suitability in the two contrasting settings. Three possible explanations are offered for the combined soils and vegetation results.

1. Soil and vegetation characteristics do not control presence but do significantly affect some aspect of life history such as establishment, reproduction or survival.

2. Biological processes associated with dispersal and establishment control presence, whether in place of, or in addition to the constraints imposed by soils and vegetation characteristics.

3. There are as-yet unmeasured parameters associated with the White River Formation that determine presence. This will be evaluated further when mineralogy results become available, and may or may not point to the presence of toxic metals or metalloids in the soils or water retention properties.

Thorough analysis of soils data awaits mineralogy results because we have not found any unique soil properties in *Yermo*1 habitat that would confer instability. It may have unique susceptibility to wind erosion, as suggested by Bynum (1993). Determination of the water-holding properties of the soils and the water budgets of the plants may also prove useful as they integrate many environmental variables in arid settings.

There are outstanding research tasks and additional lines of research suggested by results to date, that include the following:

1. Analysis of water release curves for all soils collected in 2010.

2. Further analysis with existing datasets, including the NSSC data, compared with 2010 data results.

3. Mycorrhizal symbiosis warrants additional work on the quantitative levels of infection and species involved.

4. Direct analysis of toxic metals or metalloids.

5. Evaluation of the comparatively high organic matter documented in *Yermo*1 soils. Perhaps there is fossil organic matter in the matrix of parent material.

6. Sources of nitrogen in the system may warrant closer investigation.

Completion of this stage of investigation and review of all supporting research products (population documentations, digitized survey routes, potential distribution model, photograph files) is provided as reference for current research underway (monitoring, pilot research in mycorrhizal relationships and pilot research in physiology).

CONCLUSIONS

The four investigations of *Yermo* distribution and habitat requirements complement one another in ways that we could not have anticipated. Botanists can speculate about some hypothetical overlooked pocket of potential habitat but it is no more than speculation without having a way to apply Geographic Information Systems tools to overlay past surveys routes upon maps or aerial imagery. We cannot say that either the photointerpretation or the modeling were the sole tool for identifying the site which ultimately proved to harbor a second *Yermo* population. This is because both were considered in demarcating targets and they both identified suitable habitat in the same locale.

Methodological products of this project include four digitized sets of negative survey results and a refined potential distribution model for reference. There are a limited number of polygons identified in the hybrid model and also in the Fertig and Thurston (2003) model that have not been surveyed. We expect to conduct a follow-up survey after this report is submitted in final form, and survey results will be submitted as an electronic addendum with cover memo to complete systematic inventory of all high probability habitat that we can identify by these methods.

This project addresses the previously-identified need to survey for new populations in areas identified as potential suitable habitat (USDI Fish and Wildlife Service 2010). Information products of this project include documentation of a second *Yermo* population and a refined profile of soil and vegetation characteristics. This project also addresses what had been identified as a major threat for *Yermo*, the possibility that one catastrophic natural or human caused event could lead to extinction.

Paradoxically, habitat conditions at the two *Yermo* populations contrast with one another. This makes for a more complicated picture in the quest to understand why *Yermo* occurs in some areas and not in others. Direct comparison of the Regional Maxent Model parameters and soils results suggest that there could be common denominators between remote sensing themes and soil conditions at one or both populations (Table 5).

Table 5. Comparison between Regional Maxent Model parameters and soils results

Regional Maxent Model Parameter	**Corresponding Soil Result**	**Comments**
Soil Texture, correlated with high silt fraction	Silt Content (%)	The model and soils results converge over silt content in *Yermo*1 soil attributes, but differ sharply in *Yermo*2 soil attributes.
Potential for Rock Outcrop	Organic Matter (LOI), Soil Color	The sparseness of vegetation and limited soil development are indirectly reflected in soil results for both *Yermo* populations.

It would be premature to interpret the contrasting soils and vegetation of the two populations as equally suitable, until population growth rates in the two settings are available as indicating relative suitability. Information on the respective population origin and relations between the two *Yermo* populations would also put habitat data into context

The two sites share other parameters, such as southern aspect, depth to shallowest restrictive layer, annual total radiation, radiation of the lightest month, wettest quarter mean temperature and annual relative humidity range. However, these may only serve as indicators of erosion potential or vegetation sparseness.

The responses we see in final models are usually proxies for some more direct but immeasurable factor that is really controlling distribution. In other words, the relationships we see between occurrence and the predictor variables probably reflect real correlations, but we should be careful about drawing too strong an inference about causation.

Mineralogy information is needed to evaluate the hypothesis that the high volcanic ash content of soils at the *Yermo*1 site confers a stress or instability to which the species is adapted as a narrow endemic. The soil parent materials at the two sites are apparently from the same geological formation but have significantly different properties.

Soil-water release curves and water budgets of the species are needed to evaluate the hypothesis that Yermo has the capacity to take up water under a wide range of hydrological conditions, and that soil-plant relationships are affected in some way by this information in combination with mineralogy.

The ecological amplitude of *Yermo* suggests that it is not restricted, or at least not completely restricted, by habitat requirements. This places a premium on getting detailed population growth rates and life history information from demographic monitoring for the two contrasting habitats. The results of this report belong in any *Yermo* recovery plan as slated for development according to the recovery outline (USDI Fish and Wildlife Service 2010). They also belong in the Lander Resource Management Plan slated for update by Bureau of Land Management, with a framework for managing *Yermo*. Finally, *Yermo* critical habitat designation might be reconsidered by Fish and Wildlife Service in light of information provided in this document.

LITERATURE CITED

Barber, S.A. 1995, 2nd ed. *Soil Nutrient Availability*: *A Mechanistic Approach*. John Wiley & Sons, Inc. New York, NY.

Barkley, T.M. 1999. The segregates of *Senecio*, s.l. and *Cacalia*, s.l., in the flora of North America north of Mexico. SIDA 18: 661-672.

Benninghoff, W.S. 1966. The releve method for describing vegetation. The Michigan Botanist. 5: 109-114.

Beyer, H. L. 2004. Hawth's Analysis Tools for ArcGIS. Available at http://www.spatialecology.com/htools.

Bynum, M. 1993. Soil characterization at desert yellowhead site. Term project for Soils 5120. University of Wyoming, Laramie, WY.

Cutler, D. Richard, Edwards, Thomas C., Jr., Beard, Karen H., Cutler, Adele, Hess, Kyle T., Gibson, Jacob, Lawler, Joshua J. (2007). Random forests for classification in ecology. Ecology, 88(11): 2783-2792.

Dorn, R.D. 1991. *Yermo xanthocephalus* (Asteraceae: Senecioneae): A new genus and species from Wyoming. Madroño 38(3): 198-201.

Dorn, R.D. 2001. *Vascular Plants of Wyoming*, 3rd ed. Mountain West Publishing, Cheyenne, WY. 412 pp.

Dorn, R.L. 2006. *Yermo*. In: Flora of North America Editorial Committee, eds. 1993+. *Flora of North America North of Mexico*. Vol. 20. Magnoliophyta: Asteridae (in part): Asteraceae part 2. Oxford University Press, New York and Oxford. pp. 634-635.

Elith, J., C. H. Graham, R. P. Anderson, M. Dudik, S. Ferrier, A. Guisan, R. J. Hijmans, F. Huettmann, J. R. Leathwick, A. Lehmann, J. Li, L. G. Lohmann, B. A. Loiselle, G. Manion, C. Moritz, M. Nakamura, Y. Nakazawa, J. M. Overton, A. T. Peterson, S. J. Phillips, K. Richardson, R. Scachetti-Pereira, R. E. Schapire, J. Soberon, S. Williams, M. S. Wisz, and N. E. Zimmermann. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography 29:129-151.

Fertig, W. 1994. Survey form and entered occurrence record for *Yermo xanthocephalus* #001. Wyoming Natural Diversity Database, unpublished data.

Fertig, W. 1995. Status report on *Yermo xanthocephalus* in central Wyoming. Unpublished report prepared for the BLM Wyoming State Office and Rawlins District by the Wyoming Natural Diversity Database. Laramie, WY.

Fertig, W. and R. Thurston. 2001. Draft model for *Yermo xanthocephalus.* In-house reference. Wyoming Natural Diversity Database. Laramie, WY.

Fertig, W. and R. Thurston. 2003. Modeling the potential distribution of BLM Sensitive and USFWS Threatened and Endangered plant species in Wyoming. Unpublished report prepared for the Bureau of Land Management Wyoming State Office by Wyoming Natural Diversity Database, University of Wyoming, Laramie, WY.

Fielding, A.H. and Bell, J.F. 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation 24: 38-49.

Greaves, R. K., R. A. Sanderson, and S. P. Rushton. 2006. Predicting species occurrence using information-theoretic approaches and significance testing: An example of dormouse distribution in Cumbria, UK. Biological Conservation 130:239-250.

Guisan, A. and W. Thuiller. 2007. Predicting species distribution: offering more than simple habitat models. Ecology Letters 10:435-435.

Heidel, B. 2002. Status report on desert yellowhead (*Yermo xanthocephalus*) in Wyoming. Prepared for the Bureau of Land Management by the Wyoming Natural Diversity Database, Laramie.

Heidel, B. 2007. Wyoming plant species of concern. Wyoming Natural Diversity Database, Laramie, WY.

Heidel, B. and J. Handley, W. 2010. Survey form and entered occurrence record for *Yermo xanthocephalus* #002. Wyoming Natural Diversity Database, unpublished data.

Hernandez, Pilar A., Graham, Catherine H., Master, Lawrence L. & and Albert, Deborah L. (2006). The effects of sample size and species characteristics on performance of different species distribution modeling methods. Ecography, 29: 773-785.

Keinath, D.A., M.D. Andersen and G.P. Beauvais. 2010. Range and modeled distribution of Wyoming's vertebrate species of greatest conservation need. Report prepared by the Wyoming Natural Diversity Database, Laramie Wyoming for the Wyoming Game and Fish Department, Cheyenne, Wyoming and the U.S. Geological Survey, Fort Collins, Colorado.

Koch, K. and K. Mengel. 1974. The influence of potassium nutritional status on the absorption and incorporation of nitrate nitrogen. Plant Analysis and Fertilizer Problems Proc. of Seventh Int. Coll. 1: 209-218.

Madden, S. 2005. Changes in soil physical properties and vegetation following long-term grazing removal in Wyoming sagebrush steppe. Masters Thesis. Department of Renewable Resources, University of Wyoming, Laramie, WY.

McCune, B. and J.B. Grace. 2002. Analysis of Ecological Communities. MJM Software Design, Gleneden Beach, Oregon.

McMillan, M.E., P.L. Heller and S.L. Wing. 2006. History and causes of post-Laramide relief in the Rocky Mountain orogenic plateau. Geological Society of America Bulletin 118(3/4): 393-405.

Opler, Paul A., Kelly Lotts, and Thomas Naberhaus, coordinators. 2011. Butterflies and Moths of North America. Bozeman, MT: Big Sky Institute. http://www.butterfliesandmoths.org/

(Version 4-21-2011).
Phillips, Steven J. No date. A brief tutorial on Maxent. Accessed 05-04-2011 at: http://www.cs.princeton.edu/~schapire/maxent/tutorial/tutorial.doc.

Phillips, Steven J., Dudík, Miroslav and Schapire, Robert E. 2004. A Maximum Entropy Approach to Species Distribution Modeling. Proceedings of the 21rst International Conference on machine learning. New York, NY.

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

Scott, R.W. 2000. Field studies on *Yermo xanthocephalus* Dorn. Report prepared for the Bureau of Land Management. Department of Biology, Central Wyoming College, Riverton, WY.

Scott, R. and B. Hoster. 2000. On the germination and viability of *Yermo xanthocephalus* akenes. *Castilleja* 19(1): 4-6.

Scott, R.W. and B.J. Scott. 2009. *Yermo xanthocephalus* Dorn - A Research Report. Prepared for Bureau of Land Management. Central Wyoming College Herbarium and Scott Environmental Resources, Inc. in cooperation with Wyoming Natural Diversity Database. Riverton, WY.

Simley, J.D. & Carswell Jr., W.J. (2009). The National Map--Hydrography: U.S. Geological Survey Fact Sheet 2009-3054.

USDA Soil Survey Staff. 2010. National Soil Characterization Data. Posted online at: http://soils.usda.gov/survey/nscd/.

USDA, Soil Survey Laboratory Information Manual. 2011 (February). Burt, Rebecca (compiler and editor). Soil Survey Investigation Report No. 45, Version 2.0. National Soil Survey Center, Lincoln, Nebraska. Available only on line at: ftp://ftp-fc.sc.egov.usda.gov/NSSC/Lab_Info_Manual/ssir45.pdf .Accessed 12-05-2011.

USDI Bureau of Land Management. 1998. Draft *Yermo xanthocephalus* (Desert Yellowhead) Conservation Agreement, Assessment and Strategy. 17 pp.

USDI Bureau of Land Management. 2005a. Environmental Assessment (WY050-EA5-040), Protective Withdrawal Desert Yellowhead (WYW142589). Lander Field Office, Fremont County, Wyoming. May 2005.

USDI Bureau of Land Management. 2005b. Notice of emergency closure of public lands to motorized vehicle use. Federal Register Vol. 70, No. 132:40053.

USDI Fish and Wildlife Service. 1998. Endangered and Threatened Wildlife and Plants: Threatened status for the plant *Yermo xanthocephalus*. Federal Register 63(245): 70745-70751.

USDI Fish and Wildlife Service. 2002. Endangered or Threatened species; Listing the Desert Yellowhead as Threatened. Federal Register 67(50): 11442-11449.

USDI Fish and Wildlife Service. 2005. Amended programmatic biological opinion for the Wyoming Bureau of Land Management Lander Resource Management Plan and Bureau conservation measures and the effects to the Desert Yellowhead (*Yermo xanthocephalus*).

USDI Fish and Wildlife Service. 2010. Recovery outline for *Yermo xanthocephalus* (desert yellowhead). Posted electronically at: http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=Q3GI#conservationPlans

Williams, S. 2010. Preliminary analysis of National Soil Characterization Data for seven samples in Fremont County. Unpublished summary table.