USE OF MODELLING IN A GEOGRAPHIC INFORMATION SYSTEM TO PREDICT GREATER SAGE-GROUSE HABITAT

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ABSTRACT In Colorado (and across many western States) the Bureau of Land Management (BLM) is in the process of producing a greater sage-grouse (*Centrocercus urophasianus* [sage-grouse]) Resource Management Plan Amendment and Environmental Impact Statement (RMPA and EIS) for the BLM's Northwest Colorado District, to assess impacts of potentially implementing sage-grouse habitat management conservation strategies (BLM 2013). If approved, the RMPA and EIS would amend current BLM Resource Management Plans and U.S. Forest Service Land and Resource Management Plans that would guide the management of greater sage-grouse habitat on public lands administered by the BLM and the U.S. Forest Service and on private lands with a federal nexus to the BLM planning process (e.g., projects extracting federal minerals or accessing federal lands across private lands). A key component of implementing sage-grouse conservation strategies is accurately predicting where sage-grouse habitat occurs; however, the current sage-grouse Preliminary Priority Habitat and Preliminary General Habitat used in the RMPA and EIS was in large part based on habitat modeling conducted at large scales (Doherty et al. 2010, Rice et al. 2013), which makes land use planning, accurate impact assessments and project implementation at the project level difficult due to the inherent inaccuracies of large scale habitat maps. We employed two different methods to map and quantify at a finer and more accurate scale the extent of suitable sage-grouse habitat found in Garfield County, Colorado. We started by mapping vegetation at a 2 m^2 cell resolution in order to capture nuances in sage-grouse habitats given sage-grouse preference of habitat at smaller scales (Connelly et al. 2000, Hagen et al. 2007), and then employed: (1) a weighted overlay as a habitat suitability index (HSI) using a resource selection function (RSF) and (2) fuzzy modeling at 10 m^2 cell resolution. We validated this technique against sage-grouse signage data from pedestrian surveys documenting where evidence of sage-grouse occupancy had occurred and lek location data.

KEY WORDS *Centrocercus urophasianus*, greater sage-grouse, fuzzy model, resource selection model, habitat suitability index, Geographic Information System (GIS).

Within the Piceance, Parachute, Roan (PPR) area, there have been a number of studies investigating greater sage-grouse (*Centrocercus urophasianus* [sage-grouse]) and the uniqueness of the habitats in this area (Braun 1995, Hagen 1999, Apa 2006, Apa et al. 2007, Colorado Parks & Wildlife [CPW] 2008, Sauls et al. 2006-2008, WestWater Engineering [WWE] 2008, Walker et al.

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2010[3], and Apa et al. 2010[4]). The PPR area habitats are known for the steepness of habitats, the variety in vegetation conditions, and the limited spatial extent of “typical” sage-grouse habitats. Additionally, the number of studies in the PPR is also due to a combination of the significant mineral resources in this area; primarily natural gas and oil shale, but also the presence of sage-grouse and the atypical habitat found in this area. Instead of the large expanses of rolling sagebrush (*Artemisia tridentata*) steppe typically occupied by sage-grouse (Knick and Connelly 2011, Sage-grouse National Technical Team 2011), the PPR area has narrow ridgelines supporting sagebrush, which quickly grade into mixed mountain shrub habitats and other unsuitable habitat types on side slopes (Apa 2006). Of note, is that the rough topography and patches of non-habitat do not appear to pose a movement barrier to sage-grouse (Apa 2006, Apa et al. 2007, WWE 2008). Because of the mineral resources, energy company exploration and energy development is very common; much of the private lands within the PPR area are owned by energy companies. Energy companies have funded a number of CPW, consultant, and university studies in this area, and of these studies a number have been focused on mapping the unique habitats and discerning how sage-grouse utilize these atypical habitats (Hagen 1999, Sauls et al. 2006, 2008, WWE 2008, Apa et al. 2007, 2010 and Walker et al. 2010).

Of all the studies reviewed, they have all been relatively consistent with reporting how sage-grouse utilize habitats in the PPR area; sage-grouse are still strongly associated with sagebrush-dominated habitats, generally at the higher elevations, and favor sagebrush-dominated habitats at multiple spatial scales. In other words, sage-grouse favor larger areas of sagebrush dominated habitats, but can also be found in smaller patches of sagebrush. As these patches get smaller, or occur in landscapes more dominated by unsuitable habitats (e.g., mixed mountain shrublands), their use of sagebrush habitats can decline (Apa 2006, Apa et al. 2007, WWE 2008). Sage-grouse in the PPR area are unique in that their occupied habitats are much smaller in spatial extent and patch size when compared to other more “typical” sage-grouse habitats occupied by other populations (Connelly et al. 2000, et al. 2004). Sage-grouse also are found to utilize sagebrush habitats with a notable presence of other shrub species (e.g., snowberry [*Symphoricarpos oreophilus*], Utah serviceberry [*Amelanchier utahensis*]), but generally when these other shrub species occupy >25% of the shrub component, sage-grouse use of these areas appears to decline based on preliminary research (Sauls et al. 2006-2008, Apa et al. 2007, WWE 2008).

We have found that there have been multiple efforts to map suitable sage-grouse habitats in the area, and all are fairly accurate and relevant (given the acknowledged limitations of the data and methods employed). Some of the more accurate habitat maps have likely been “hand draw” or delineated from aerial imagery and topography (e.g., Sauls et al. 2006-2008, WWE 2008), but this technique is difficult or impossible to repeat, and is highly dependent upon the knowledge and biases of the authors conducting the habitat delineations. Nevertheless, these products appear to be very accurate when compared to on-the-ground conditions.

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[3] The information in Walker et al. 2010 is considered preliminary and subject to further evaluation, therefore our research does not utilize or rely on this information, and our citation of this work is for general information regarding CPW’s in-process investigations.

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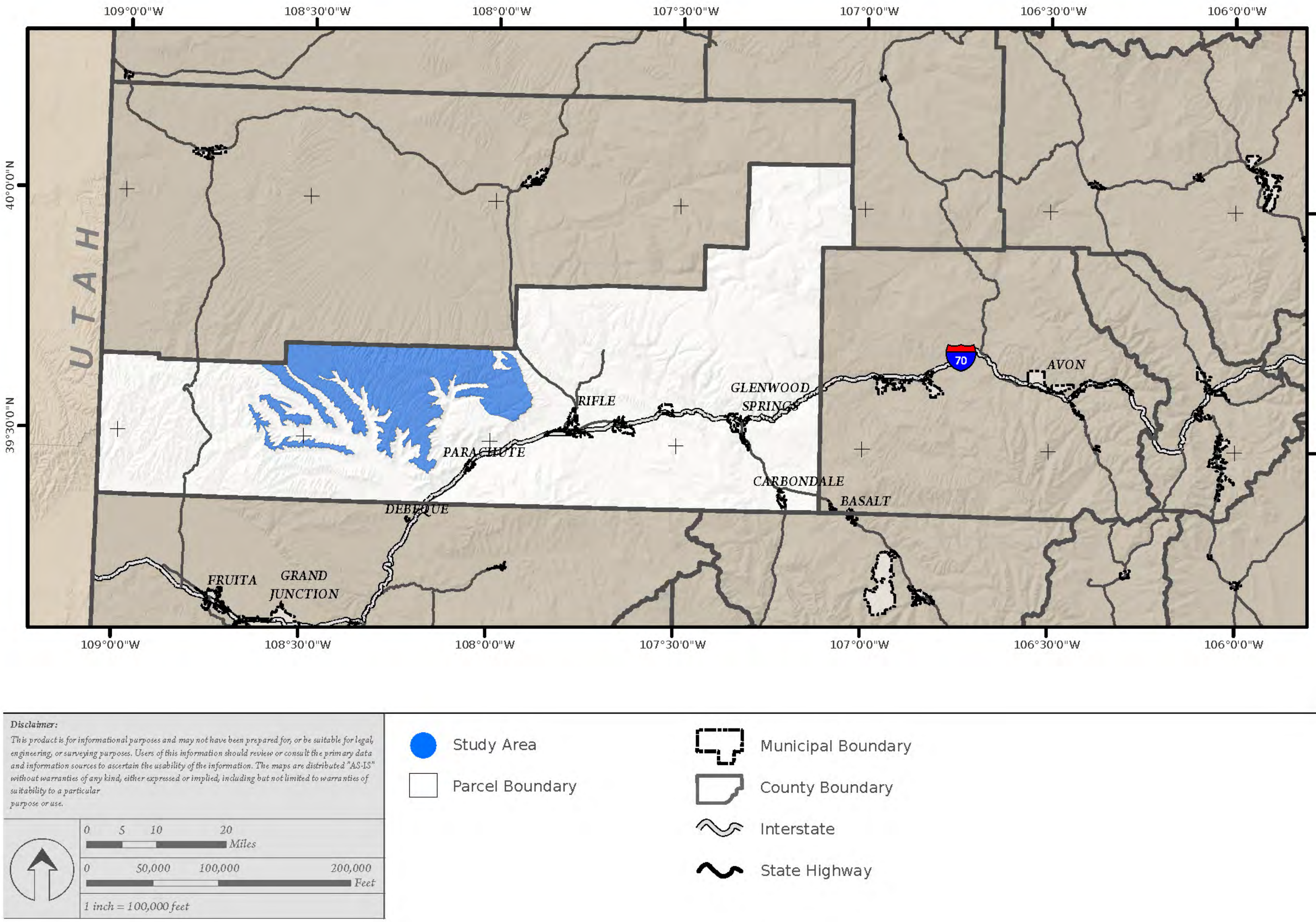
Rice et al. (2013) published their sage-grouse habitat mapping technique which was used to develop Preliminary Priority Habitat and Preliminary General Habitat (PPH and PGH) habitat maps in Colorado, including the PPR area. When compared to previous habitat mapping efforts produced by the BLM, private consultants, and interim work by CPW (Sauls et al. 2006-2008, WWE 2008, Walker et al. 2010), the PPH and PGH mapping appeared to over-predict habitat. Despite available vegetation datasets, their model was not able to discern between the sagebrush and sagebrush-mixed mountain shrubland habitats known to be used by sage-grouse, and the non-habitat areas of steeper draws, canyons, aspen (*Populus tremuloides*) stands, contiguous mixed mountain shrubland or Douglas-fir (*Pseudotsuga menziesii*) stands in the PPR area.

Because of the large change in previous characterizations of sage-grouse habitat in Garfield County to what is now shown in PPH and PGH maps, we attempted a new, repeatable habitat modelling technique in a Geographic Information System (GIS) to accurately locate and quantify the availability of suitable greater sage-grouse habitat in the PPR area within Garfield County (PPR Study Area), independent of maps already produced by the BLM, CPW, or other interested parties (including energy companies, which have performed a number of sage-grouse habitat mapping efforts). Yet we still incorporated the data that documented existing sage-grouse research, information, data and peer-reviewed and accepted habitat parameters for sage-grouse in development of our suitable habitat model. Predictive models that locate and quantify the availability of suitable habitats for a given species are predominately based on quantifying the relationships between species selection and surrounding environmental factors. This paper discusses the two different methods used to map and quantify the extent of suitable sage-grouse habitat found in the PPR area: (1) weighted overlay as a habitat suitability index (HSI) using a resource selection function (RSF) and (2) fuzzy modeling.

Figure 1: The PPR Study Area in Colorado.



In recent years, the approaches to modelling species habitat availability have advanced significantly, providing a number of statistically rigorous methods for predicting and evaluating species distribution (Rushton et al. 2004, Guisan and Thuiller 2005). Our approach to mapping and quantifying the extent of suitable sage-grouse habitat within the PPR Study Area utilized two distinctly different methods of modeling within a geospatial environment; (1) weighted overlay modeling using an RSF and (2) fuzzy modeling. The weighted overlay approach using an RSF was selected for three reasons. First, weighted overlay models, commonly known as Habitat Suitability Indexes (HSI), are widely accepted and employed by State and Federal wildlife agencies to model species distribution for resource management, planning and population viability analyses, including the U.S. Fish and Wildlife Service (USFWS) Habitat Evaluation Program (HEP) (USFWS 1980, 1981). Secondly, weighted overlay models have previously been employed, and are currently being employed in other ongoing research projects to study sage-grouse habitat availability, which provides results from our efforts as a means for direct comparison to other RSF and HSI models in Colorado (Sauls et al. 2008, Walker et al. 2010, Rice et al. 2013). Third, using an RSF allows species distribution to be modeled using known selection preferences from statistical inference of field-collected data, thereby predicting suitable habitat patches based on known behavior of the local population. By contrast, the application of fuzzy modeling to predict species distribution has been much more limited to date; however, at least one study has occurred whereby fuzzy logic was employed to map suitable sage-grouse and mule deer habitats in northwest Colorado (Hibbs 2011). This method is gaining acceptance and increased utilization based on the ability of the model to consider vagueness and imprecisions inherent in the attributes of spatial data; a limitation of other model methods. Fuzzy logic is intuitive and constructed using natural language, allowing the reasoning behind a fuzzy system to be simple and easily understood by a wide variety of audiences (Mathworks 2014a). For this reason, we also selected the fuzzy model approach to predict species habitat distribution within the PPR Study Area.

Weighted Overlay and Resource Selection Function

Weighted overlay models function by applying logical mathematical arithmetic to multiple criteria, allowing for diverse and dissimilar criteria to be inputs to an integrated analysis (Mathworks 2014a). In the instance of an HSI, the model scales, weights and integrates diverse spatial data to measure the habitat suitability of a given location on a common, relative scale. Furthermore, an HSI can employ two methods in developing the criteria as inputs to the model framework; inductive (i.e., empirical, inferred from existing data) or deductive (i.e., non-empirical, developed from expert opinion). We pursued an inductive approach to our habitat modeling for two reasons: (1) we had access to spatially-explicit field-collected data of sage-grouse sign and occupancy, and (2) deductive approaches have the possibility of introducing bias from expert-opinion.

An RSF model is a form of an HSI with statistical rigor (Boyce et al. 2002); it is a mathematical function that predicts resource or habitat use proportional to probability of use (Manley et al. 2002). While other models are developed based on expert opinion, RSF models are estimated directly from empirical data (Boyce et al. 2002). Empirical models analyze a species' habitat selection by relating known occurrences of the species (presence) with data quantifying background environmental variables. An RSF model predicts species distribution based on the theory of habitat selection; where habitat use exceeds availability, habitat selection is inferred; and where habitat use is less than availability, habitat avoidance is inferred (Johnson and Gillingham 2005).

An RSF is generally developed from observations of either presence vs. absence or presence vs. available resource units. Both methods employ a logistic regression model utilizing a binary response (observation) that either implies presence (y=1) or absence or random location (y=0). For each observation, a set of measured habitat criteria exist, χ. For the probability of occurrence [$P(y=1|\chi)$], the dependent variable can be estimated with the following equation:

$$P(y=1|\chi) = \left(\frac{\exp(\beta_0 + \beta_1\chi_1 + ... + \beta_p\chi_p)}{1+\exp(\beta_0 + \beta_1\chi_1 + ... + \beta_p\chi_p)} \right)$$

where $(\beta_0 ... \beta_p)$ are maximum likelihood estimates of logistic regression coefficients and $(\chi_1 ... \chi_p)$ represent values for environmental criteria as a set of independent variables (Pearce and Boyce 2006). The equation returns values on a continuous scale of zero to one, with higher values indicating a higher level of habitat suitability.

Fuzzy Modeling

Behavioral and environmental phenomena are inherently complex, demonstrating vagueness and uncertainty that are difficult to express with crisp class boundaries. Most phenomena do not have clearly defined boundaries and are better expressed linguistically with degrees of membership to a set, rather than forcing a rigid classification to a single class (Kainz 2008). Fuzzy systems are a method that handles vagueness and uncertainty in spatial data. Fuzzy logic recognizes that most objects cannot be defined as belonging to one specific category or another (Zadeh 1965). When applied to habitat models, species presence does not imply absolute favorability or absolute un-favorability, but rather a degree of favorability.

Fuzzy inference is the process of mapping linguistic terms to an output using a fuzzy logic system. Generally speaking, fuzzy inference involves three steps: (1) identifying input terms and constructing linguistic if-then rules, (2) defining fuzzy sets and assigning fuzzy membership and (3) performing fuzzy overlay with a fuzzy operator.

The objective of fuzzy inference is to use the set of if-then statements to map results to an output space. The if-then statements, also known as fuzzy rules, refer to explanatory variables and adjectives that describe them. Fuzzy rules are constructed with both an antecedent and a consequent; the “if” portion of a statement is the antecedent, while the “then” portion of the statement is the consequent (Mathworks 2014b). Prior to developing the set of fuzzy rules, all variables must first be identified including their descriptive adjectives.

A typical rule in a fuzzy system may take the following form:

If A_1 is X_1, And A_2 is X_2,… And A_n is X_n, Then B is Y.

where *X,…Xn* and *Y* are fuzzy sets defined by *A1… A_n* fuzzy membership functions. In natural language, the form may be expressed as: "If site is flat and site is near water, then site is optimal."

Once all fuzzy rules are established for the fuzzy system, fuzzy sets are developed based on the pre-defined rules. Fuzzy logic is based on classical set theory, whereby an element must be either fully part of a set or fully excluded from a set; such a set is known as a "crisp" set. Extending this theory, fuzzy logic is based on fuzzy sets that allow for various degrees of membership to a class rather than forcing a response whereby the element is either asserted or denied.

For example, when considering proximity to an existing object, the distance of a given location may be described as near or far. In a classical set, the elicited response is binary in nature; the distance of the location to the object is either near or far. However, in a fuzzy set, the same distance can be described as both near and far.

Elements are related to a fuzzy set by fuzzy membership functions. Fuzzy membership assigns a fuzzy score for an element to a class based on a sliding scale between zero and one, where zero implies no membership and one implies full membership. The membership functions transform explanatory data in terms of suitability to a continuous scale of 0 to 1 using a variety of functions and arithmetic operators. The transformation method utilized depends on how the data are distributed and contribute to suitability. While numerous fuzzy membership functions exist, three fuzzy membership functions were utilized in this analysis; fuzzy linear membership, fuzzy small membership and fuzzy large membership. These membership functions are demonstrated in Figures 2 through 4.

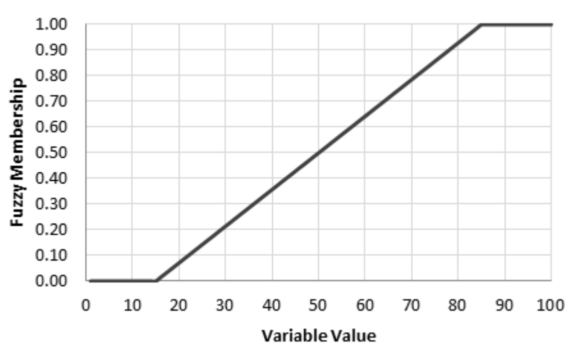
Figure 2: Fuzzy linear membership function

Fuzzy Linear Membership

Equation:

$$\mu(x) = 0 \text{ if } x < \min,$$
$$\mu(x) = 1 \text{ if } x > \max,$$
$$\mu(x) = \frac{(x - \min)}{(\max - \min)}$$

Description
A linear increasing or decreasing membership between user-specified minimum and maximum inputs.



Required Inputs
Min: *User-defined value to assign threshold for non-membership*
Max: *User-defined value to assign threshold for full membership*

Figure 3: Fuzzy small membership functions

Fuzzy Small Membership

Equation:

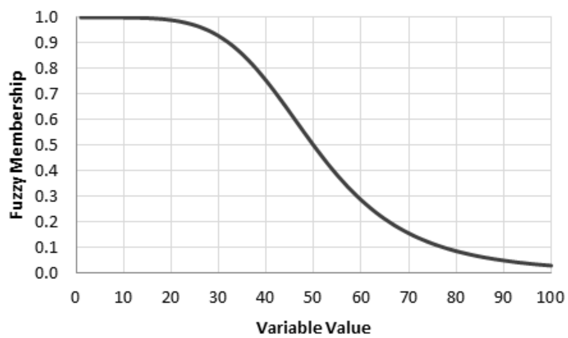
$$\mu(x) = \frac{1}{1 + \left(\frac{x}{f_2}\right)^{f_1}}$$

f_1 = spread

f_2 = midpoint

Description

Sigmoid curve function where shape is defined by a user-specified midpoint and spread. Lower variable values are assigned higher degrees of membership.



Required Inputs

Midpoint: *User-defined value to specify crossover point; assigned 0.5 membership value. Values lower than the midpoint have a higher degree of membership; values higher than the midpoint have a lower degree of membership.*

Spread: *User-defined value to prescribe the shape and character of the sigmoid curve.*

Figure 4: Fuzzy large membership function

Fuzzy Large Membership

Equation:

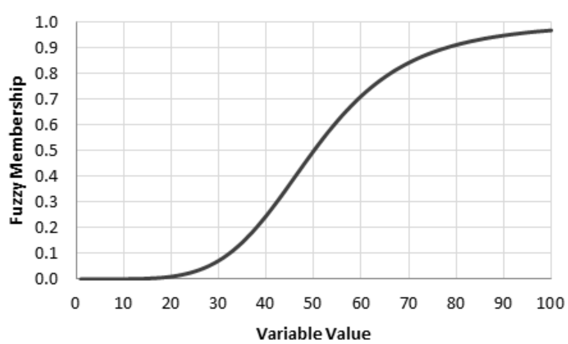
$$\mu(x) = \frac{1}{1 + \left(\frac{x}{f_2}\right)^{-f_1}}$$

f_1 = spread

f_2 = midpoint

Description

Sigmoid curve function where shape is defined by a user-specified midpoint and spread. Higher variable values are assigned higher degrees of membership.



Required Inputs

Midpoint: *User-defined value to specify crossover point; assigned 0.5 membership value. Values higher than the midpoint have a higher degree of membership; values lower than the midpoint have a lower degree of membership.*

Spread: *User-defined value to prescribe the shape and character of the sigmoid curve.*

When all explanatory data have been transformed to membership data, fuzzy overlay functions are used to combine the data to produce a single truth value that ranges in degree from 0 to 1. Once all inputs are fuzzified, the degree to which each part of the antecedent is satisfied for each rule is known (Mathworks 2014b). The overlay functions investigate the relationship between membership data and attempt to quantify the interaction between them, ultimately returning the degree of membership to the final set for all areas included in the analysis. The fuzzy overlay functions are listed and described in Figure 5. The fuzzy model returns a raster dataset with cell values ranging on a continuous scale from zero to one, with higher values indicating a higher degree of truth.

Figure 5: Fuzzy overlay functions

Overlay Function	Equation	Description
Fuzzy AND	$= Min(\chi_1, \chi_2, \ldots \chi_n)$	*Decreasing function. Fuzzy AND returns the minimum value of all sets at each cell location.*
Fuzzy OR	$= Max(\chi_1, \chi_2, \ldots \chi_n)$	*Increasing function. Fuzzy OR returns the maximum value of all sets at each cell location.*
Fuzzy PRODUCT	$= \chi_1 * \chi_2 \cdots \chi_n$	*Decreasing function. For each cell location, Fuzzy PRODUCT multiplies the fuzzy values of each set.*
Fuzzy SUM	$= 1 - ((1 - \chi_1) * (1 - \chi_2) \ldots (1 - \chi_n))$	*Increasing function. For each cell location, Fuzzy SUM adds the fuzzy values of each set.*
Fuzzy GAMMA	$= (1 - ((1 - \chi_1) * (1 - \chi_2) \ldots (1 - \chi_n)))^{\gamma} * (\chi_1 * \chi_2 \cdots \chi_n)^{1-\gamma}$	*Increasing/Decreasing function. Fuzzy GAMMA is the product of Fuzzy PRODUCT and Fuzzy SUM, both raised to the power of gamma.*

Study Area

The 894 km^2 project Study Area occurs on the Roan Plateau within Garfield County, at the southern end of the Piceance Basin in an area known as the PPR area (PPR Study Area, Figure 1). The spatial extent of the analysis area represents all areas within Garfield County currently indicated as PPH and PGH as mapped by CPW (Rice et al. 2013) and adopted by the BLM in their Resource Management Plan Amendment/ Environmental Impact Statement (RMPA and EIS) for the BLM's Northwest Colorado District. Our study area is limited to just Garfield County within the greater PPR area. Of the Study Area, 248-km^2 (28%) of surface lands are managed by the BLM, while the remaining 646-km^2 (72%) are private and State lands. Land use in the Study Area continues to be managed for summertime cattle ranching and energy development of primarily natural gas, with some limited oil shale resource exploration.

Vegetation is relatively heterogeneous, and was dependent upon slope, aspect, and elevation. Three subspecies of big sagebrush occupy the Study Area, and the location of these subspecies is dependent upon soil type. Basin big sagebrush (*Artemisia tridentata* subsp. *tridentata*) is the prevalent vegetation throughout the lower drainages at elevations of 1,800 m – 1,980 m (Cottrell and Bonham 1992). *A. t. wyomingensis* is restricted to upland ridges at elevations of 1,900 m – 1,980 m (Cottrell and Bonham 1992). *A. t. vaseyana* is confined to high mountain areas at elevations > 2,070 m. Pinyon pine (*Pinus edulis*) and juniper (*Sabina* [*Juniperus*] *osteosperma* and *S. scopulorum*) woodlands dominate the landscape until approximately 1,980 m. Big sagebrush, Utah serviceberry, oakbrush (*Quercus gambelii*), and antelope bitterbrush (*Purshia tridentata*) comprise most of the transitional ecotone vegetation type. Pinyon-juniper habitat types are relatively uncommon within the PPR Study Area in Garfield County, and were much more common to the north in Rio Blanco County where elevations are lower. Elevations of 2,380 m to 2,590 m are dominated by big sagebrush interspersed with grass and forb-dominated meadows. North aspects often host substantial groves of aspen, serviceberry, and mountain snowberry. Big sagebrush and Douglas-fir dominate south and northwest aspects at elevations > 2,500 m respectively. Free water can be scarce in dry years or late in the summer as most springs are in the bottom of steep canyons. There are scattered stock tanks and dugouts for watering cattle, which are usually associated with roadways.

METHODS

Biophysical Habitat Factors

Numerous variables were considered in our analysis that may influence sage-grouse habitat selection. The variables were broadly classified as either habitat characteristics or topographical factors. All variables describing habitat characteristics were derived from a digital vegetation map developed at a 2-m^2 cell resolution through supervised image classification of 1-m^2 color-infrared aerial photography collected in 2012 as part of the National Agricultural Imagery Program (NAIP) administered by the U.S. Department of Agriculture (USDA 2012). A detailed description of the image classification process is provided in Appendix A. Vegetation cover types derived from the image classification process are displayed in Figure 6. Topographic variables were derived from a 10-meter digital elevation model (DEM) acquired from the U.S. Geologic Survey (USGS), National Elevation Dataset. Topographic variables considered in this analysis include percent slope, topographic position index (TPI) and surface roughness, or curvature. Percent slope were derived directly from the 10-meter USGS DEM. TPI is a relative measure of a locations elevation, or slope position, as compared to surrounding elevations or positions. TPI was calculated using Jenness Enterprises DEM Surface Tools v. 2.1.375. Curvature, or surface roughness, was developed by computing the standard deviation of slope within a defined neighborhood.

Vegetation variables were developed as percent proportion of specified vegetation communities within a defined scale; likewise, all topographic variables were derived as mean values within a defined scale. All variables were analyzed and considered at three spatial scales, because while sage-grouse are known as a landscape level species, most of the contemporary research documenting sage-grouse use has been performed at the local scale. The scales of available habitats that influence sage-grouse selection and non-use are currently unknown; therefore, the contributing variables that may influence habitat selection are tested at multiple scales to determine which scales guide habitat selection. The selected scales employed in this analysis represent a local scale (e.g., 100 meters), an intermediate scale (e.g., 350 meters) and a landscape-level scale (e.g., 1 kilometer). While the distances are somewhat arbitrary (i.e., a distance of 300 or 400 meters would equally be considered an intermediate scale), they reflect distances used in other contemporary studies of sage-grouse habitat selection conducted both within the PPR Study Area and the defined national range. At each scale, statistics were generated using a moving circular window across the project Study Area, at distances of 100 m, 350 m and 1 km, respectively. A detailed summary of all variables considered in the scope of this analysis are presented in Table 1. Table 2 shows the summary of explanatory variables at 939 sites indicating sage-grouse presence in the defined analysis area.

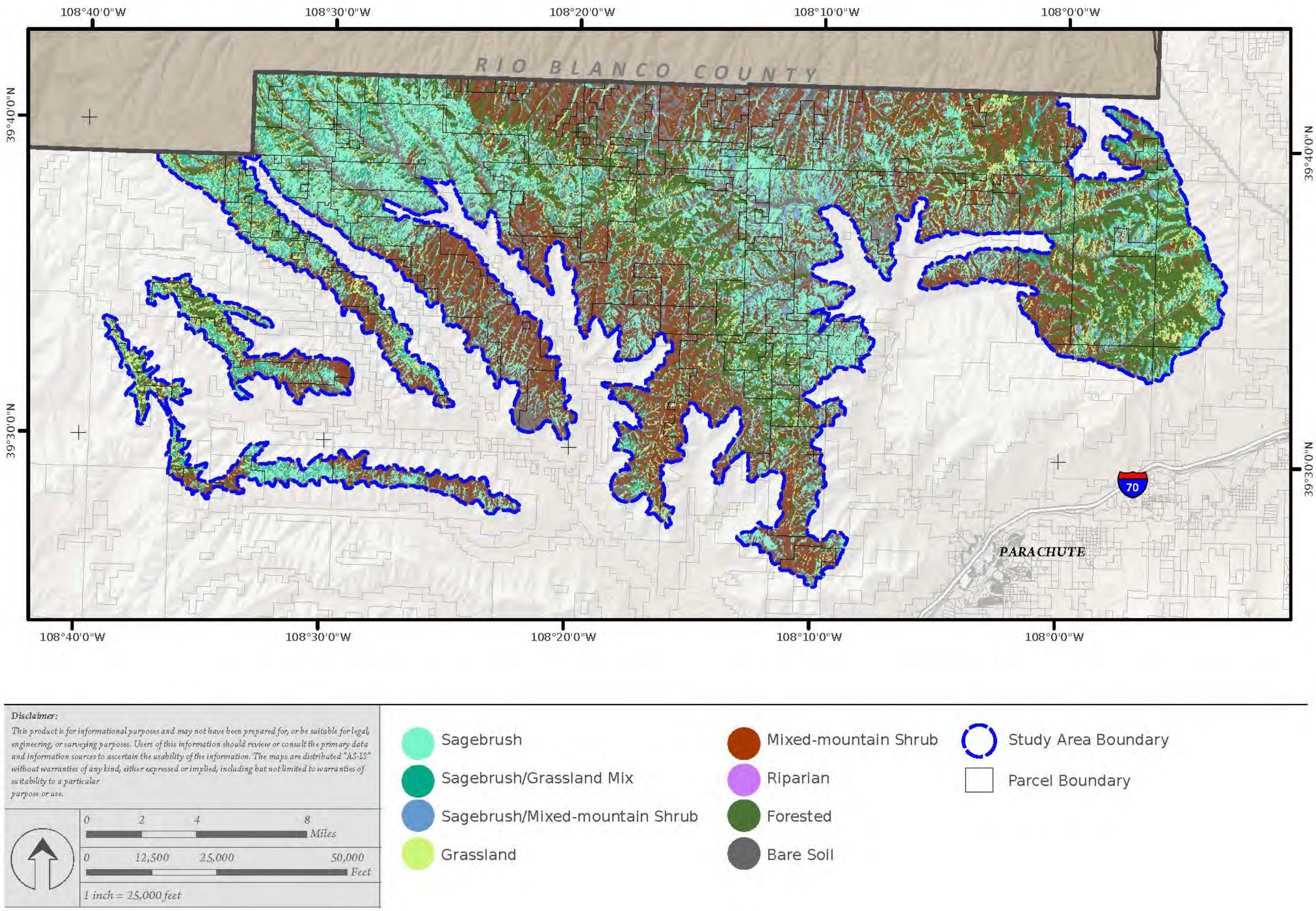
Table 1: Summary and Description of all Explanatory Variables. Summary and description of all explanatory variables used in assessing sage-grouse habitat suitability in the defined analysis area.

Variable	Name	Description
Vegetation		
sg100	Sage-dominated, 100-meters	*Percent proportion of all sage-dominated vegetation communities within a 100-meter radius.*
sg350	Sage-dominated, 350-meters	*Percent proportion of all sage-dominated vegetation communities within a 350-meter radius.*
sg1k	Sage-dominated, 1-kilometer	*Percent proportion of all sage-dominated vegetation communities within a 1-kilometer radius.*
sgmms100	Sage-dominated + mixed mountain shrubs, 100-meters	*Percent proportion of all sage-dominated and mixed mountain shrub vegetation communities within a 100-meter radius.*
sgmms350	Sage-dominated + mixed mountain shrubs, 350-meters	*Percent proportion of all sage-dominated and mixed mountain shrub vegetation communities within a 350-meter radius.*
sgmms1k	Sage-dominated + mixed mountain shrubs, 1-kilometer	*Percent proportion of all sage-dominated and mixed mountain shrub vegetation communities within a 1-kilometer radius.*
mms100	Mixed mountain shrubs, 100-meters	*Percent proportion of all mixed mountain shrub vegetation communities within a 100-meter radius.*
mms350	Mixed mountain shrubs, 350-meters	*Percent proportion of all mixed mountain shrub vegetation communities within a 350-meter radius.*
mms1k	Mixed mountain shrubs, 1-kilometer	*Percent proportion of all mixed mountain shrub vegetation communities within a 1-kilometer radius.*
sggr100	Sage-dominated + grasslands, 100-meters	*Percent proportion of all sage-dominated and grassland vegetation communities within a 100-meter radius.*
sggr350	Sage-dominated + grasslands, 350-meters	*Percent proportion of all sage-dominated and grassland vegetation communities within a 350-meter radius.*
sggr1k	Sage-dominated + grasslands, 1-kilometer	*Percent proportion of all sage-dominated and grassland vegetation communities within a 1-kilometer radius.*
gr100	Grasslands, 100-meters	*Percent proportion of all grassland vegetation communities within a 100-meter radius.*
gr350	Grasslands, 350-meters	*Percent proportion of all grassland vegetation communities within a 350-meter radius.*
gr1k	Grasslands, 1-kilometer	*Percent proportion of all grassland vegetation communities within a 1-kilometer radius.*
bare100	Barren surface, 100-meters	*Percent proportion of all bare surface within a 100-meter radius.*
bare350	Barren surface, 350-meters	*Percent proportion of all bare surface within a 350-meter radius.*
bare1k	Barren surface, 1-kilometer	*Percent proportion of all bare surface within a 1-kilometer radius.*
for100	Forested areas, 100-meters	*Percent proportion of all forested vegetation communities within a 100-meter radius.*
for350	Forested areas, 350-meters	*Percent proportion of all forested vegetation communities within a 350-meter radius.*
for1k	Forested areas, 1-kilometer	*Percent proportion of all forested vegetation communities within a 1-kilometer radius.*
for_dist	Distance to forest	*Distance to forested areas.*
Topographic		
slope100	Percent slope, 100-meters	*Mean percent slope within a 100-meter radius.*
slope350	Percent slope, 350-meters	*Mean percent slope within a 350-meter radius.*
slope1k	Percent slope, 1-kilometer	*Mean percent slope within a 1-kilometer radius.*
tpi100	Topographic position index, 100-meters	*Mean topographic position index within a 100-meter radius.*
tpi350	Topographic position index, 350-meters	*Mean topographic position index within a 350-meter radius.*
tpi1k	Topographic position index, 1-kilometer	*Mean topographic position index within a 1-kilometer radius.*
curve100	Curvature, 100-meters	*Mean curvature within a 100-meter radius.*
curve350	Curvature, 350-meters	*Mean curvature within a 350-meter radius.*
curve1k	Curvature, 1-kilometer	*Mean curvature within a 1-kilometer radius.*

Table 2: Summary of Explanatory Variable. Summary of explanatory variables at 939 sites indicating Greater Sage-grouse presence in the defined analysis area.

Variable	Mean ± Std. Dev.	Median	25% - 75% Quartiles	Min.	Max.
Vegetation					
sg100	0.7348 ± 0.2549	0.7981	0.5757 – 0.9606	0.0	1.0
sg350	0.6339 + 0.2278	0.6819	0.4792 – 0.8229	0.0183	0.9725
sg1k	0.5441 + 0.1935	0.5662	0.3852 – 0.712	0.0794	0.8579
sgmms100	0.8117 + 0.2206	0.8886	0.6963 – 0.9973	0.0	1.0
sgmms350	0.8046 + 0.1219	0.8229	0.7355 – 0.9098	0.2744	0.9725
sgmms1k	0.7472 + 0.0896	0.7674	0.6804 – 0.8166	0.406	0.9367
mms100	0.0792 + 0.1363	0.0	0.0 – 0.112	0.0	1.0
mms350	0.1707 + 0.1647	0.1226	0.0177 – 0.2908	0.0	0.7918
mms1k	0.203 + 0.1546	0.1936	0.0571 – 0.3236	0.0046	0.7236
sggr100	0.6589 + 0.2944	0.7056	0.4456 – 0.9324	0.0	1.0
sggr350	0.5556 + 0.2523	0.5729	0.3455 – 0.7901	0.0032	0.9777
sggr1k	0.4736 + 0.1993	0.4687	0.3265 – 0.6536	0.0719	0.8721
gr100	0.0127 + 0.0407	0.0	0.0 – 0.0	0.0	0.5066
gr350	0.0236 + 0.0305	0.0119	0.0018 – 0.0329	0.0	0.2354
gr1k	0.0267 + 0.0203	0.0227	0.0123 – 0.0364	0.0	0.1782
bare100	0.1642 + 0.2082	0.0883	0.0 – 0.2429	0.0	1.0
bare350	0.134 + 0.1119	0.0897	0.0496 – 0.1968	0.0	0.7104
bare1k	0.1596 + 0.0891	0.1472	0.087 – 0.2032	0.0205	0.4628
for100	0.0088 + 0.0463	0.0	0.0 – 0.0	0.0	0.511
for350	0.0378 + 0.0646	0.0048	0.0 – 0.0514	0.0	0.439
for1k	0.0663 + 0.0621	0.049	0.018 – 0.1042	0.0	0.3586
for_dist	452.19 + 396.17	320.16	190.26 – 551.73	0.0	2,568.6
Topographic					
slope100	17.08 + 6.93	15.98	11.6 – 21.65	4.6167	45.1652
slope350	25.43 + 5.39	25.3	21.26 – 28.84	13.8007	44.647
slope1k	29.28 + 3.72	28.78	26.5 – 31.55	23.0494	40.4389
tpi100	483.93 + 22.0	482.42	468.24 – 501.61	384.584	551.082
tpi350	463.76 + 18.29	464.6	452.22 – 478.16	405.514	520.361
tpi1k	442.38 + 11.77	444.83	435.05 – 451.61	405.554	465.649
curve100	7.9699 + 2.7441	7.604	5.838 – 9.8535	2.7412	19.3061
curve350	11.1652 + 2.4527	11.134	9.2925 – 12.6971	6.0214	20.107
curve1k	12.738 + 1.725	12.4362	11.4627 – 13.9053	10.0158	17.5551

Figure 6: Vegetation Types. Vegetation types within the PPR Study Area derived from image classification of color-infrared National Agricultural Imagery Program (NAIP) aerial photography collected in 2012.



Spatial Data Collection

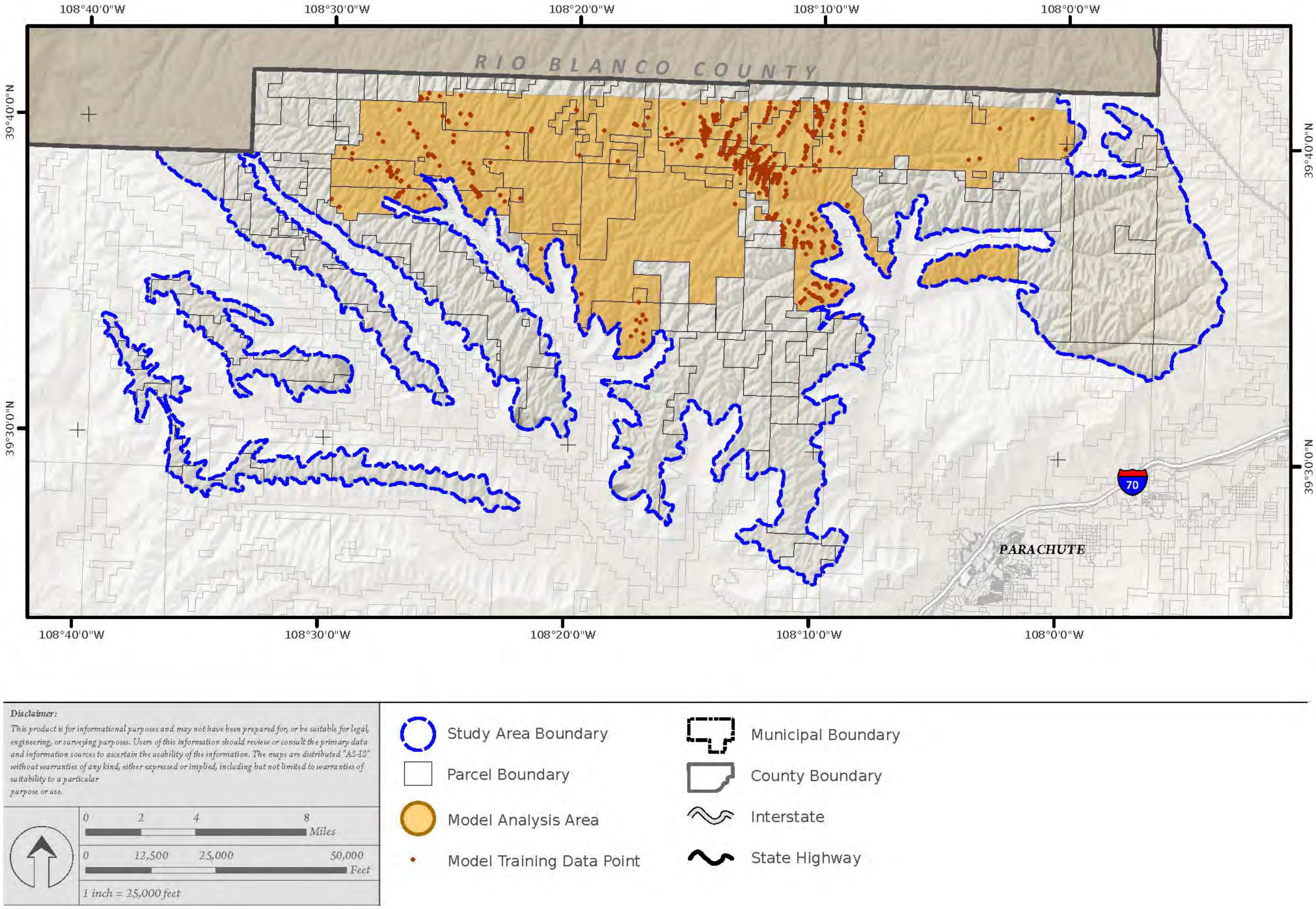
Field-collected data of point locations of sage-grouse signage were collected and compiled from three individual private landowners within the PPR Study Area (WWE 2008). In total, the compiled dataset contained 1,174 unique signage points collected from 2005 to 2012 across a contiguous area totaling 375 km^2 completely contained within the broader PPR Study Area (WWE 2008). The private lands where the field surveys were conducted occur in the central portion of the broader PPR Study Area and are considered to be representative of the diverse habitat types that naturally occur in the region; the surveyed area is displayed on Figure 7. The signage point data consisted of locations indicating presence of sage-grouse, including feather and pellet presence, lek locations and physical bird sightings collected during the summer season when the PPR Study Area is snow-free and easily accessible. All signage data were collected using resource-grade Global Positioning Systems (GPS) with an assumed 2-m horizontal precision. No telemetry data (i.e., sage-grouse outfitted with a GPS or radio-collar) were available for use in this analysis. Prior to, and after the acquisition of the sage-grouse point data, there has been a number of natural gas exploration and development activities in the analysis area, including road construction, natural gas pad development, compressor station construction, and other natural gas related support facilities. Because of these activities and the changing landscape, we did not attempt to capture these habitat impacts in our analysis, as it would have been very difficult to draw a point-in-time by which to incorporate these anthropogenic impacts. An incorporation of these habitat impacts could be incorporated into subsequent modelling analysis investigating direct and indirect impacts to sage-grouse habitats, but such an analysis was beyond the scope of our efforts.

While this data can show presence and seasonality of use, interpretation of how sage-grouse were using the area (e.g., summer foraging, winter foraging and nesting) is somewhat subjective and difficult to accurately predict. Some sage-grouse sign (such as roost piles) can reliably be used to predict winter time use, but single pellets, feathers, or tracks were assumed to not provide enough data to accurately describe use, therefore our models do not attempt to discern how habitats are being utilized by sage-grouse.

Analysis Area

While the model analysis area covered the entire extent of the 894-km^2 PPR Study Area, the model was trained on available point locations collected within the 375-km^2 acres of private lands. The training area, displayed in Figure 7, occurs in the central portion of the broader PPR Study Area, containing a variety of habitat types and topographical features that are assumed to represent the diverse topography and vegetation communities of the broader PPR Study Area.

Figure 7: *Model training area. Defined area used for habitat model training and locations of signage points collected from 2005-2012 within the broader PPR Study Area.*



Resource Selection Function

We first assessed suitability of sage-grouse habitat using a weighted overlay approach utilizing a RSF. The RSF was constructed on a presence vs. available habitat design because our data contained presence-only records, with no attempt to track absence locations. The presence vs. available habitat design characterizes a sample of sites where species' presence is recorded from a sample of resources available in the surrounding environment (Boyce et al. 2002). By contrast, a presence vs. absence design characterizes a sample of sites where species' presence is recorded by contrasting a sample of resources in sites the species are known to be absent. A concern with the presence vs. absence approach is the potential for a false negative error for presence thereby introducing potential bias to the model. While we can ensure that presence records indicate species use, we cannot say with certainty that unused sites (or absence records) are not actually utilized (Boyce et al. 2002). By contrast, a presence vs. available habitat design allows for contamination, defined as having a mixture of both used and unused resources present in the random sample of available resource units. This approach estimates habitat selection using a logistic function that transforms available resource distribution into the used distribution (Johnson et. al. 2006)

The field-collected sage-grouse data contained 1,174 unique point features (WWE 2008). For model analysis, we implemented a 5 to 1 training-to-validation ratio which is commonly recommended in k–fold partitioning designs to reduce cross-validation variance and bias (Breiman and Spector 1992). As such, 939 point features (80%) were randomly selected to represent presence locations; the remaining 235 point features (20%) were withheld for model validation. An additional 939 point features were randomly generated within the analysis area to quantify resource availability. In total, the compiled training dataset contained a total of 1,878 point features, with half of the features identifying known presence locations and the remaining half used for sampling available resources within the defined analysis area.

We first assessed linear correlation among the potential set predictor variables using Pearson correlation coefficients. When two parameters were correlated ($R > 0.65$), the variables were allowed to compete to determine which independent parameter better explained variance in the dependent variable. The remaining variables were tested for significance ($\rho < 0.1$) using both forward and backward stepwise selection to test all possible explanatory variable combinations and construct a model that best fit the training data; models were evaluated on the basis of samples size corrected Akaike Information Criterion (AIC) scores. AIC scores attempt to minimize model bias while maximizing model precision (Gunn et al. 2004). Models with the lowest AIC scores are considered the most parsimonious and have maximum support for the model (Goodenough et al. 2012). The selected model was further evaluated using bootstrap methods; the data was randomly re-sampled 10,000 times to generate 95% confidence intervals for regression coefficients and estimate standard errors of regression parameters. The full set of explanatory variables retained for model analyses with estimated coefficients, standard errors, upper and lower confidence intervals and significance values are summarized in Table 3. All statistical analyses were performed in the R Project for Statistical Computing using the stats (R Core Team 2013), aod (Lesnoff and Lancelot 2012), Hmisc (Harrell and Dupont 2014) and boot packages (Cantey and Ripley 2013).

After determining the best fit model, the regression coefficients obtained from the analysis were applied to the respective spatial data layers for each explanatory variable as a weighted linear combination in a GIS to produce a predictive surface.

The regression equation for the final model is expressed in the following form:

Y= -16.037746

- 1.841643 * for350

- 18.10309 * gr1k

- 1.829971 * mms100

- 2.321588 * mms1k

+ 14.394478 * sg1k

- 14.473146 * sggr1k

- 0.10506 * slope_100

- 0.122239 * slope_1k

+ 0.044144 * tpi_100

where Y is the probability of occurrence of sage-grouse.

The probability of occurrence was logit transformed using the equation:

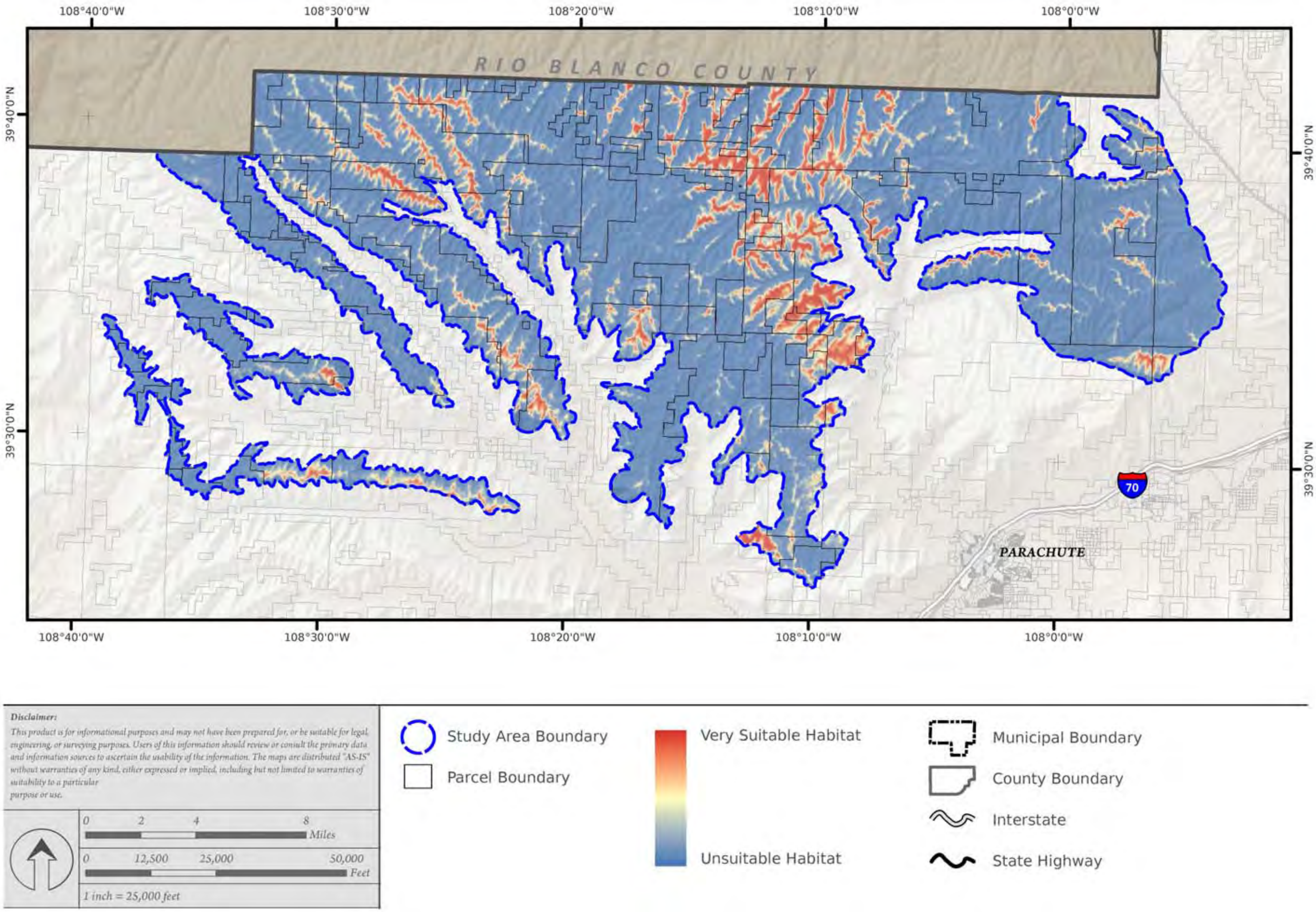
$$P = e^{Y} / (1 + e^{Y})$$

The resulting output (Figure 8) predicts probability of occurrence for sage-grouse on a continuous index of 0 to 1; 0 represents 0% probability of suitable sage-grouse habitat while a value of 1 represents 100% probability of suitable habitat for the species.

Table 3: RSF model variable coefficients. Summary of Coefficients of Explanatory Variables used to Predict Suitable Sage-Grouse Habitat

			95% Confidence Interval		
Variable	**Coefficient**	**Std. Error**	***Lower***	***Upper***	**ρ Value**
Intercept	-16.037746	3.0156	-22.811554	-10.918313	< 0.0001
sg1k	14.394478	2.229340	10.536357	19.309086	< 0.0001
mms100	-1.829971	0.698993	-3.279840	-0.542836	0.0037
mms1k	-2.321588	1.559011	-5.482815	0.583278	0.0841
sggr1k	-14.473146	2.161593	-19.251208	-10.785774	< 0.0001
gr1k	-18.103090	4.942620	-29.617783	-10.155660	< 0.0001
for350	-1.841643	1.155621	-4.152190	0.376809	0.0964
slope100	-0.105060	0.015353	-0.139571	-0.079109	< 0.0001
slope1k	-0.122239	0.047573	-0.216595	-0.031149	0.003
tpi100	0.050775	0.004596	0.044144	0.062215	< 0.0001

Figure 8: RSF model results. Raw RSF model results for PPR sage-grouse habitat.



Fuzzy Model

Following development and analysis of the RSF model, a fuzzy model was developed to model suitable sage-grouse habitat within the PPR Study Area. We utilized all explanatory variable combinations to form our fuzzy model, excluding mixed sagebrush vegetation communities (e.g., sagebrush-grassland mix and sagebrush-mixed mountain shrub mix). Unlike RSF models that determine the most significant contributing explanatory variables and assign weighted coefficients, fuzzy models utilize all sets of explanatory variables without weighting assigned. Because fuzzy logic examines the degree to which a specific location belongs to multiple sets, assigning weights to explanatory variables is illogical as increasing the weight of one factor over another does not increase the potential of belonging to one or more sets; the location is either a member of the set or not (ESRI 2014).

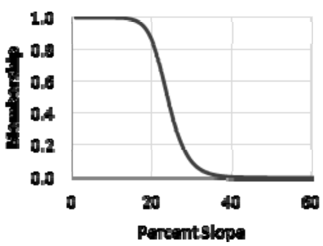
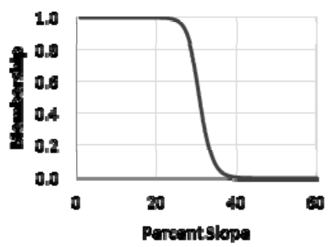
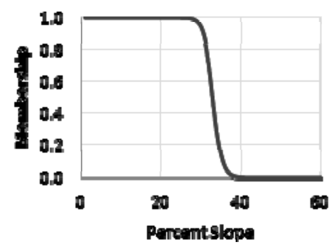
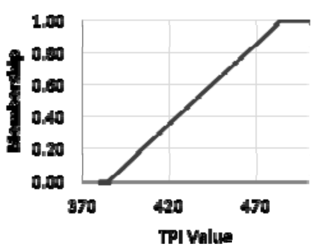
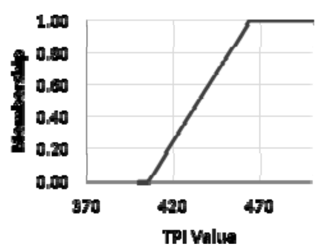
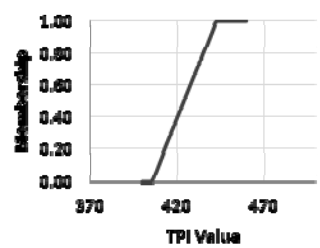
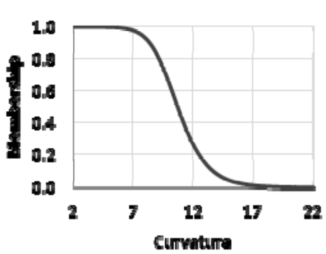
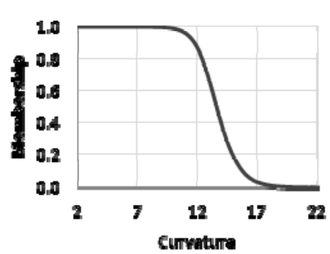
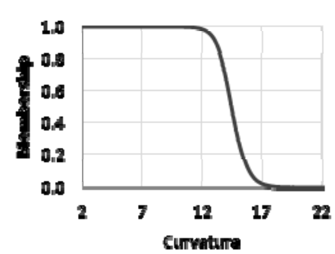
The fuzzy model was constructed to distinguish between suitable and unsuitable habitats for sage-grouse in the PPR Study Area. No attempt was made to model seasonal habitats or model effectiveness and quality of habitats. As such, the fuzzy model equation was constructed using linguistic descriptions involving all explanatory variables; the linguistic descriptions were qualified using the statistics derived for all explanatory variables listed in Table 4. The fuzzy rule for the model was developed using 25 explanatory variables.

The fuzzy memberships were fitted from the statistics gathered for each variable in Table 4. Sinusoidal memberships were formed using the variable's mean plus or minus one standard deviation for the midpoint value with a spread value that assigned near full membership at the variable's mean. Linear memberships were formed using the minimum value of the variable as the minimum point and the mean specified as the maximum point allowing full membership. The fuzzy membership equations and graphs defining probability of membership for each explanatory variable are listed in Table 5.

Table 4: Fuzzy Model Rule

A site is considered suitable for Greater Sage-grouse habitat if it meets the following criteria:		
Criteria	**Scale**	**Definition**
Slope is not steep	100 m	‘not steep’ defined as < 24%
	350 m	‘not steep’ defined as < 31%
	1 km	‘not steep’ defined as < 33%
Location is on or near a ridge	100 m	Defined as TPI value > 435
	350 m	Defined as TPI value > 435
	1 km	Defined as TPI value > 424
Surface curvature is more flat	100 m	‘more flat’ defined as < 10.71
	350 m	‘more flat’ defined as <13.62
	1 km	‘more flat’ defined as <14.46
Surrounding vegetation is dominated by sagebrush	100 m	‘dominated’ defined as > 48% presence
	350 m	‘dominated’ defined as > 41% presence
	1 km	‘dominated’ defined as > 35% presence
Proportion of mixed mountain shrubs are moderately low	100 m	‘low’ defined as < 22% presence
	350 m	‘low’ defined as <34% presence
	1 km	‘low’ defined as < 36% presence
Proportion of grasslands are low	100 m	‘low’ defined as < 5%
	350 m	‘low’ defined as < 5%
	1 km	‘low’ defined as < 5%
Presence of bare surfaces are moderately low	100 m	‘low’ defined as < 37%
	350 m	‘low’ defined as < 25%
	1 km	‘low’ defined as < 25%
Proportion forest is low	100 m	‘low’ defined as < 6%
	350 m	‘low’ defined as < 10%
	1 km	‘low’ defined as < 13%
Distance to forest is far		‘far’ defined as > 226 ft.

Table 5: Fuzzy Set Membership Functions

Percent Slope		
100 m (Local Scale)	***350 m (Intermediate Scale)***	***1 km (Landscape Scale)***
$\mu(x) = \dfrac{1}{1+\left(\dfrac{x}{24.01}\right)^{10}}$	$\mu(x) = \dfrac{1}{1+\left(\dfrac{x}{30.82}\right)^{20}}$	$\mu(x) = \dfrac{1}{1+\left(\dfrac{x}{33.0}\right)^{30}}$
		
Topographical Position Index (TPI)		
100 m (Local Scale)	***350 m (Intermediate Scale)***	***1 km (Landscape Scale)***
$\mu(x)$ = *0* if $x < 385$, $\mu(x)$ = *1* if $x > 484$, $\mu(x) = \dfrac{(x-385)}{(484-385)}$	$\mu(x)$ = *0* if $x < 406$, $\mu(x)$ = *1* if $x > 464$, $\mu(x) = \dfrac{(x-406)}{(464-406)}$	$\mu(x)$ = *0* if $x < 406$, $\mu(x)$ = *1* if $x > 442$, $\mu(x) = \dfrac{(x-406)}{(442-406)}$
		
Surface Curvature		
100 m (Local Scale)	***350 m (Intermediate Scale)***	***1 km (Landscape Scale)***
$\mu(x) = \dfrac{1}{1+\left(\dfrac{x}{10.71}\right)^{9}}$	$\mu(x) = \dfrac{1}{1+\left(\dfrac{x}{13.62}\right)^{15}}$	$\mu(x) = \dfrac{1}{1+\left(\dfrac{x}{14.46}\right)^{23}}$
		
Proportion Sagebrush		
100 m (Local Scale)	***350 m (Intermediate Scale)***	***1 km (Landscape Scale)***
$\mu(x) = \dfrac{1}{1+\left(\dfrac{x}{0.48}\right)^{-7}}$	$\mu(x) = \dfrac{1}{1+\left(\dfrac{x}{0.41}\right)^{-6}}$	$\mu(x) = \dfrac{1}{1+\left(\dfrac{x}{0.35}\right)^{-5}}$

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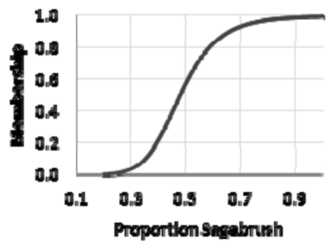
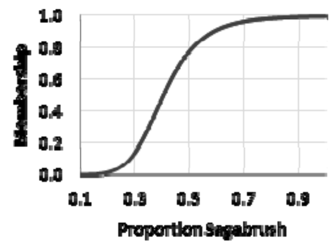
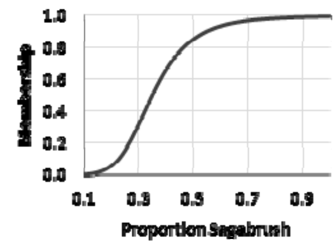
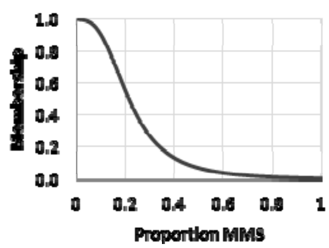
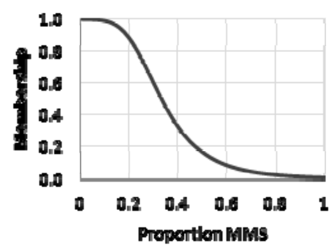
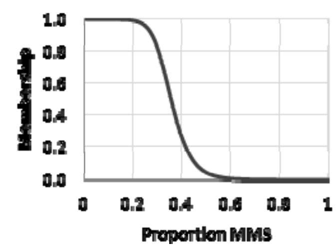
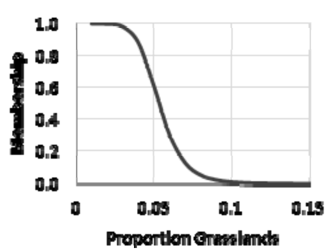
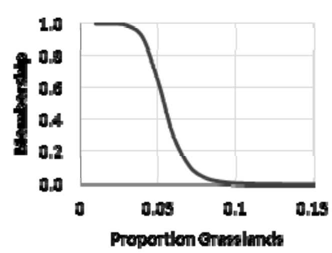
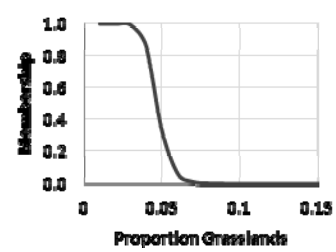
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Proportion Mixed Mountain Shrubs</td></tr>
<tr><td>100 m (Local Scale)</td><td>350 m (Intermediate Scale)</td><td>1 km (Landscape Scale)</td></tr>
<tr><td>$\mu(x) = \frac{1}{1+\left(\frac{x}{0.22}\right)^{3}}$</td><td>$\mu(x) = \frac{1}{1+\left(\frac{x}{0.34}\right)^{4}}$</td><td>$\mu(x) = \frac{1}{1+\left(\frac{x}{0.36}\right)^{9}}$</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Proportion Grasslands</td></tr>
<tr><td>100 m (Local Scale)</td><td>350 m (Intermediate Scale)</td><td>1 km (Landscape Scale)</td></tr>
<tr><td>$\mu(x) = \frac{1}{1+\left(\frac{x}{0.05}\right)^{7}}$</td><td>$\mu(x) = \frac{1}{1+\left(\frac{x}{0.05}\right)^{8}}$</td><td>$\mu(x) = \frac{1}{1+\left(\frac{x}{0.05}\right)^{11}}$</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Proportion Bare Surface</td></tr>
<tr><td>100 m (Local Scale)</td><td>350 m (Intermediate Scale)</td><td>1 km (Landscape Scale)</td></tr>
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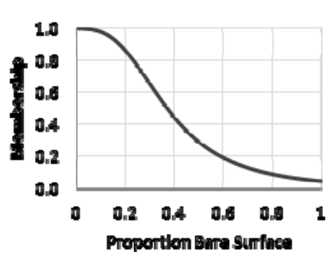
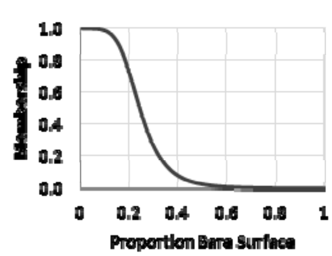
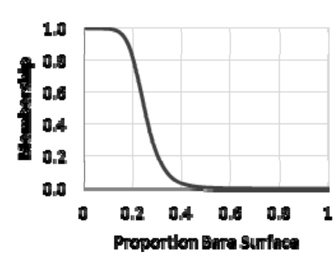
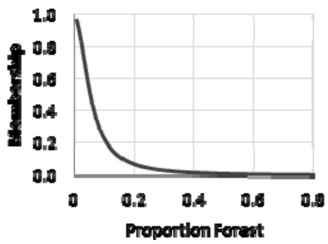
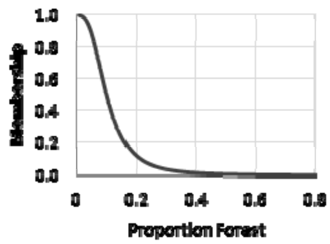
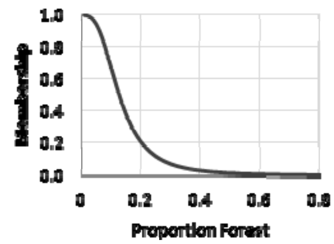
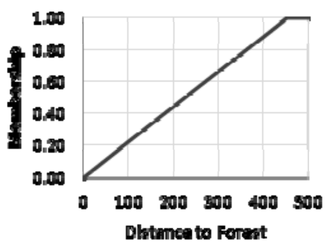
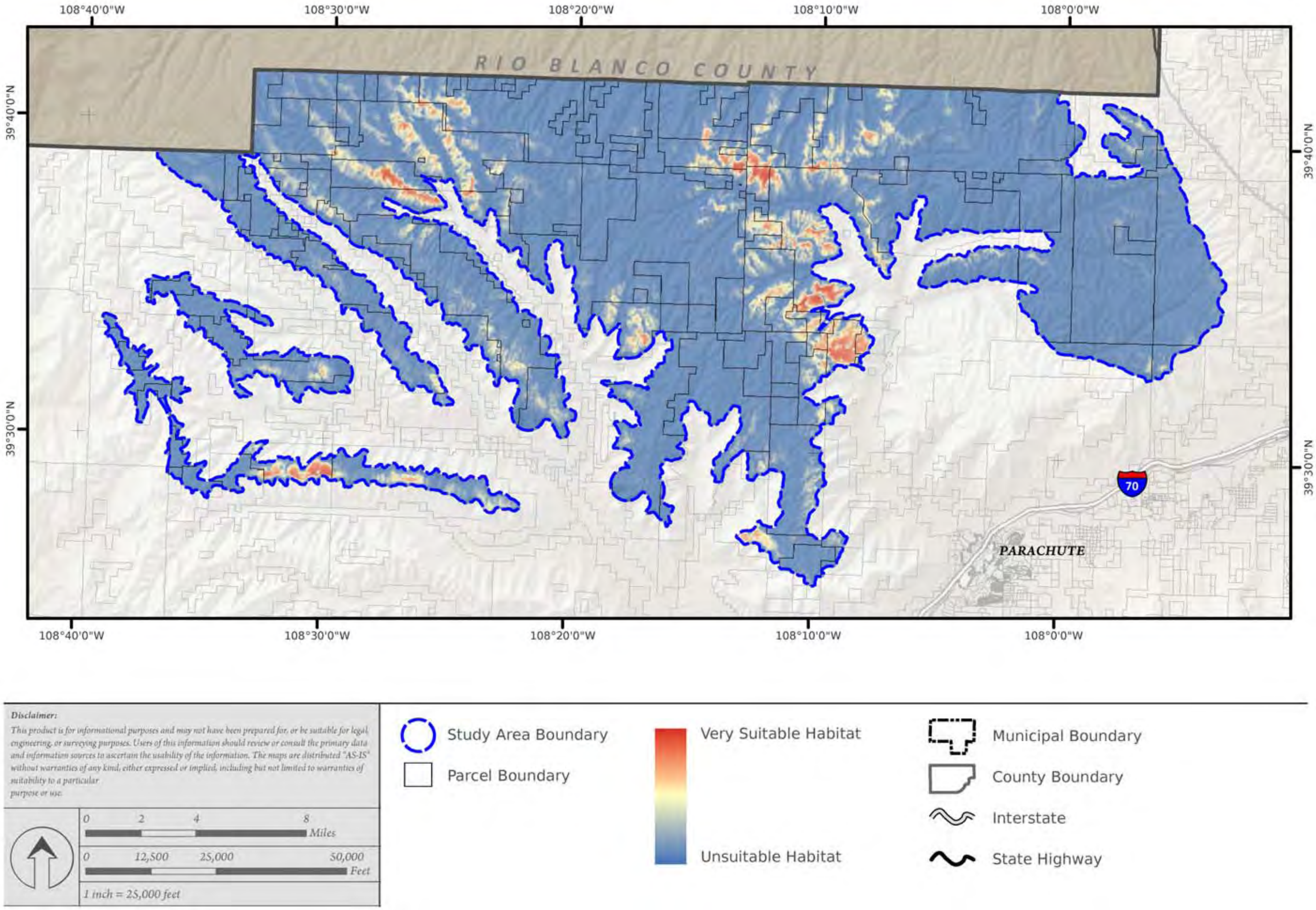
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Proportion Forest</td></tr>
<tr><td>100 m (Local Scale)</td><td>350 m (Intermediate Scale)</td><td>1 km (Landscape Scale)</td></tr>
</table>

$\mu(x) = \frac{1}{1 + \left(\frac{x}{0.06}\right)^2}$	$\mu(x) = \frac{1}{1 + \left(\frac{x}{0.10}\right)^3}$	$\mu(x) = \frac{1}{1 + \left(\frac{x}{0.13}\right)^3}$
		
Distance to Forest		
$\mu(x) = 0$ if $x < 0$, $\mu(x) = 1$ if $x > 452$, $\mu(x) = \frac{(x-0)}{(452-0)}$		
		

After fitting memberships to all model sets, the sets were combined and analyzed using the Gamma overlay operator using a gamma power of 0.9. The Gamma overlay technique is a combination of the Fuzzy Sum and Fuzzy Product overlay techniques. Fuzzy sum, an increasive function, is employed when the combination of evidence from all sets is more important than any single piece of evidence; by contrast, the Fuzzy Product technique, a decreasive function, is employed when the combination of evidence from all sets is less important than any single piece of evidence. When the Gamma value is applied as 1.0, the results are precisely the same as the Fuzzy Sum technique; when the Gamma value is 0, the results are precisely the same as the Fuzzy Product technique. Initially the Fuzzy Sum technique was employed as no single piece of evidence influenced sage-grouse habitat selection, but rather selection was determined by variety of combined factors. However, the results of the Fuzzy Sum technique ranged from 0.999 – 1.0; far too similar to accurately distinguish between habitat types and probable selection. As such, the Gamma overlay technique was employed to decrease the results, increasing the range of values returned and provide greater contrast in suitable habitats across the Study Area landscape. Initially, we knew the gamma operator would be higher to maintain the increasing function of the combined evidence. As such, we explored various results using a gamma value of 0.8, 0.85, 0.9 and 0.95. Results using a gamma operator of 0.8 and 0.85 did not adequately delineate utilized habitats, a conclusion based on observing known signage points that were not captured by the model results. By contrast, using the gamma operator of 0.95 greatly over-predicted habitat utilization, a conclusion gained by observing broad forested areas on gentler slopes delineated as suitable habitats. As such, the selected model employed a gamma value of 0.9 which maintains the increasive function of the combined evidence, yet provides adequate distinction between areas of non-utilization.

The resulting output (Figure 9) predicts probability of occurrence for sage-grouse on a continuous index of 0 to 1 using fuzzy logic; 0 represents 0% probability of suitable sage-grouse habitat while a value of 1 represents 100% probability of suitable habitat for the species.

Figure 9: Fuzzy model results. Raw fuzzy model results for PPR sage-grouse habitat.



RESULTS

RSF Model Validation

The RSF model results were validated using a k-fold cross-validation method used to correlate ranked bins with area-adjusted frequencies of predicted values (Johnson et al. 2006). The validation technique involves five steps:

Divide the resulting prediction surface into a specified number of progressively ranked equal-area bins.

Determine the midpoint value of the RSF score for each bin area.

Calculate the utilization rate for each bin using the following formula:

$$U(x_i) = w(x_i)A(x_i) / \sum_j w(x_j)A(x_j)$$

where $w(x_i)$ is the midpoint RSF value of bin i and $A(x_i)$ is the area of bin i (Boyce and McDonald 1999).

Estimate the expected number of validation records within each bin using the following formula:

$$N_i = N * U(x_i)$$

where N is the total number of validation observations used and $U(x_i)$ is the utilization function from step 3.

Calculate the observed number of validation records within each bin and regress against the predicted number of locations for each bin.

A well-fit model, one proportional to probability of use, would have a slope equal to 1, an intercept of 0, with a high R^2 value and an insignificant X^2 goodness-of-fit value (Johnson et al. 2006).

RSF Model Results

The RSF model results were split into 6 equal-area ordinal bins. The 235 field-collected presence locations withheld for model validation were cross-referenced with the ordinal bins to count the number of known observations that fell within each bin. We then determined all midpoint values to calculate the expected utilization rate $U(x_i)$ for each bin. The observed and predicted location numbers were converted to percentages to assess model performance and fit using linear regression. In addition, chi-square tests were used to assess model fit, while Spearman correlation coefficients were calculated to assess significance between predicted and observed frequencies.

The RSF model validated well, having a slope of 0.779 (95% CI: 0.626 – 0.932), an intercept of 0.037 (95% CI: -0.024 – 0.097) and an R^2 value of 0.9615. The chi-square goodness-of-fit test supported a good fit between observed and predicted frequencies (χ^2 = 18, ρ = 0.263). The top two bins predicted 97% occupancy while observed occupancy totaled 99% in bins 5 and 6, totaling 297 km^2 within the PPR Study Area (Figure 9). Bins 1-4 did not meet significance criteria, whereby occupancy would not likely occur >3% of the time (results for bins 1-4 were therefore not displayed on Figure 9).

In addition, the RSF model was validated against an independent dataset of known lek locations collected by CPW within the PPR Study Area from 1997 – 2012, containing a total of 85 unique point locations (CPW 2013). The model produced a slope of 0.926 (95% CI: 0.814 – 1.034), an intercept of 0.012 (95% CI: -0.027 – 0.051) and an R^2 value of 0.985. The chi-square goodness-of-fit test supported a good fit between observed and predicted frequencies (χ^2 = 24, ρ = 0.242).

The validation results indicate the RSF model is a good predictor for sage-grouse habitat suitability within the PPR Study Area. Model validation results are summarized in Figure 10, which shows expected versus observed proportion of presence observations for withheld validation sample (n = 235) and independent CPW lek samples (n = 85). The dashed line represents perfect fit, having a slope of 1 with intercept of 0. Solid line depicts the fitted regression with point markers displayed as black diamonds.

Figure 10: RSF model bins. RSF model habitat map for PPR sage-grouse habitat.

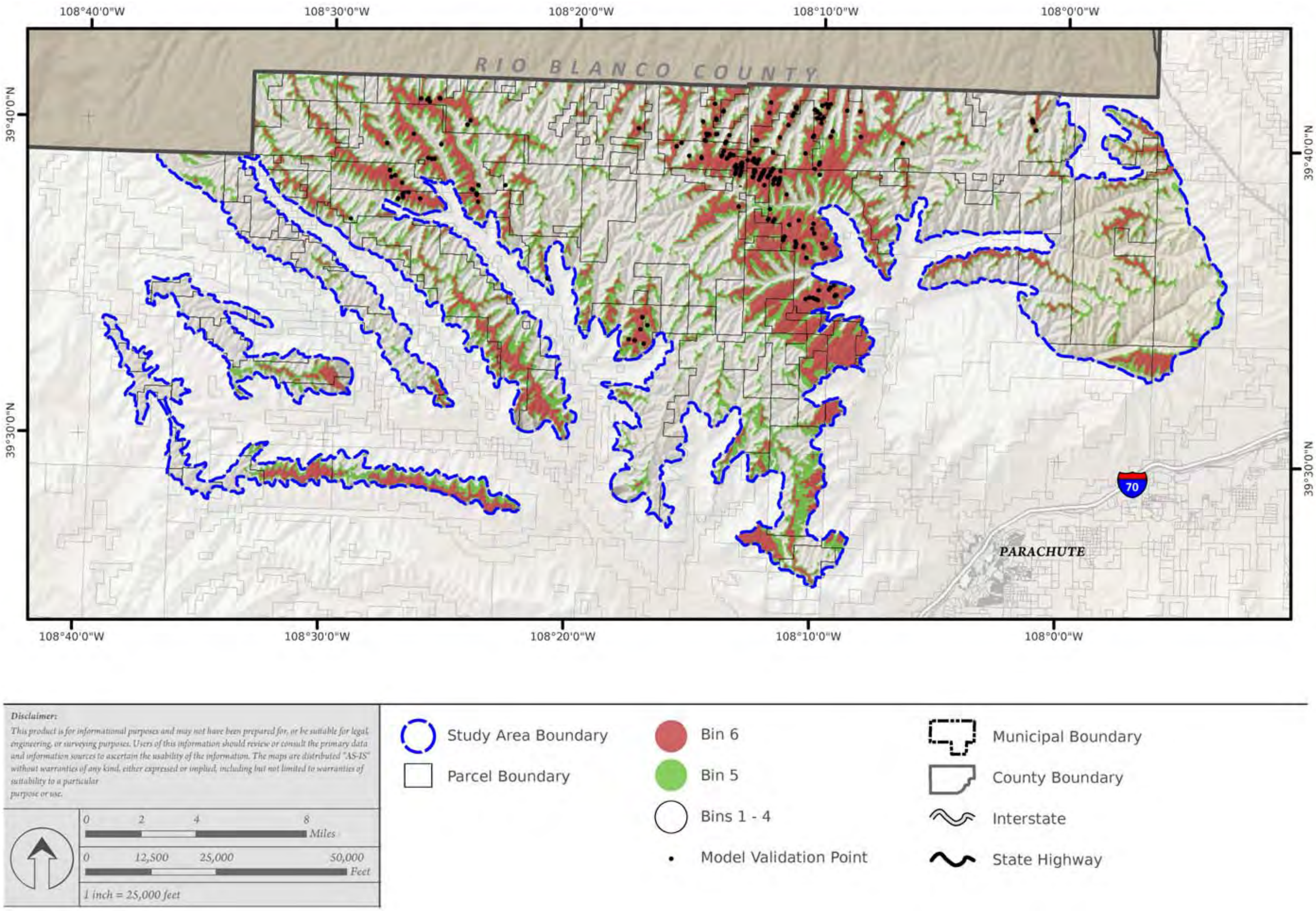
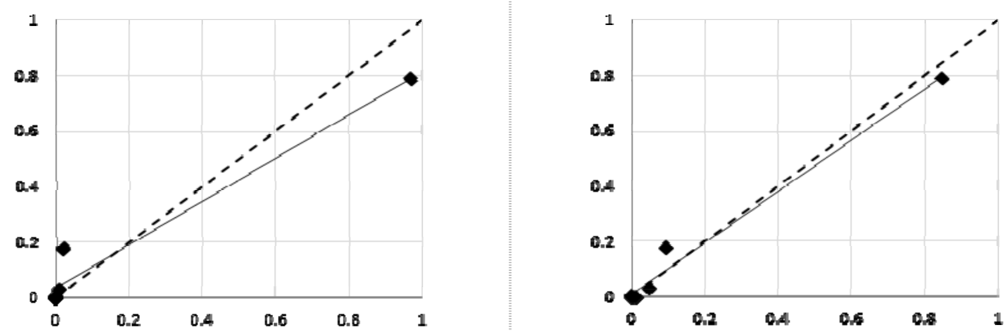


Figure 11: RSF Validation Results: Expected vs. Observed Proportion of Presence Observations.



	Withheld Validation Set			**CPW Lek Validation Set**		
Regression	$y = 0.779x + 0.037$, Adj.. r^2 **= 0.9519**			$y{=}0.926x{+}0.012$, Adj. r^2 **= 0.9814**		
Chi-square	χ^2	**Deg. Of Freedom**	ρ	χ^2	**Deg. Of Freedom**	ρ
	18	15	0.2627	24	20	0.2424
Spearman correlation	r^2	ρ		r^2	ρ	ρ
	0.9411	0.005		0.8986	0.015	0.015

Fuzzy Model Validation

Validation of the fuzzy model habitat results followed the same k-fold cross-validation procedure applied to the RSF habitat model as outlined above.

Fuzzy Model Results

Similar to the RSF model, we attempted to split the fuzzy model results into six (6) equal-area ordinal bins. However, due to the homogeneous nature of the lower values returned in the predicted surface, only four distinct bins could be produced; the lowest ranked bin (bin 1) captured approximately one-half of the study area, but due to the homogeneity of the results it could not be further subdivided. Therefore a total of four bins for the fuzzy model results are shown in Figure 12, with bin 1 being non-suitable habitat.

The 235 field-collected presence locations withheld for model validation were cross-referenced with the ordinal bins to count the number of known observations that fell within each bin. We then determined all midpoint values to calculate the expected utilization rate $U(x_i)$ for each bin. The observed and predicted location numbers were converted to percentages to assess model performance and fit using linear regression. In addition, chi-square tests were used to assess model fit, while Spearman correlation coefficients were calculated to assess significance between predicted and observed frequencies.

The fuzzy model validated very well, having a slope of 1.031 (95% CI: 0.998 – 1.064), an intercept of 0.005 (95% CI: -0.017 – 0.007) and an R^2 value of 0.999. The chi-square goodness-of-fit test supported a good fit between observed and predicted frequencies (χ^2 = 18, ρ **=** 0.1157). The top two bins (bins 3 and 4) predicted 98% occupancy and observed occupancy totaled 98% totaling 294.8 km^2 within the PPR Study Area. Bins 1-2 did not meet significance criteria, whereby occupancy would not likely occur $\geq$2% of the time (results for bins 1-2 were therefore not displayed on Figure 12).

In addition, the fuzzy model was validated against the independent dataset of known lek locations collected by CPW within the PPR Study Area from 1997 – 2012, containing a total of 85 unique point locations (CPW 2013). The model produced a slope of 1.22 (95% CI: 1.069 – 1.37), an intercept of -0.037 (95% CI: -0.083 – 0.01) and an R^2 value of 0.984. The chi-square goodness-of-fit test supported a good fit between observed and predicted frequencies (χ^2 = 24, ρ = 0.0895).

The validation results indicate the fuzzy model is a good predictor for sage-grouse habitat suitability within the PPR Study Area. Model validation results are summarized in Figure 13.

Figure 12: Fuzzy model bins. Fuzzy model habitat map for PPR sage-grouse habitat.

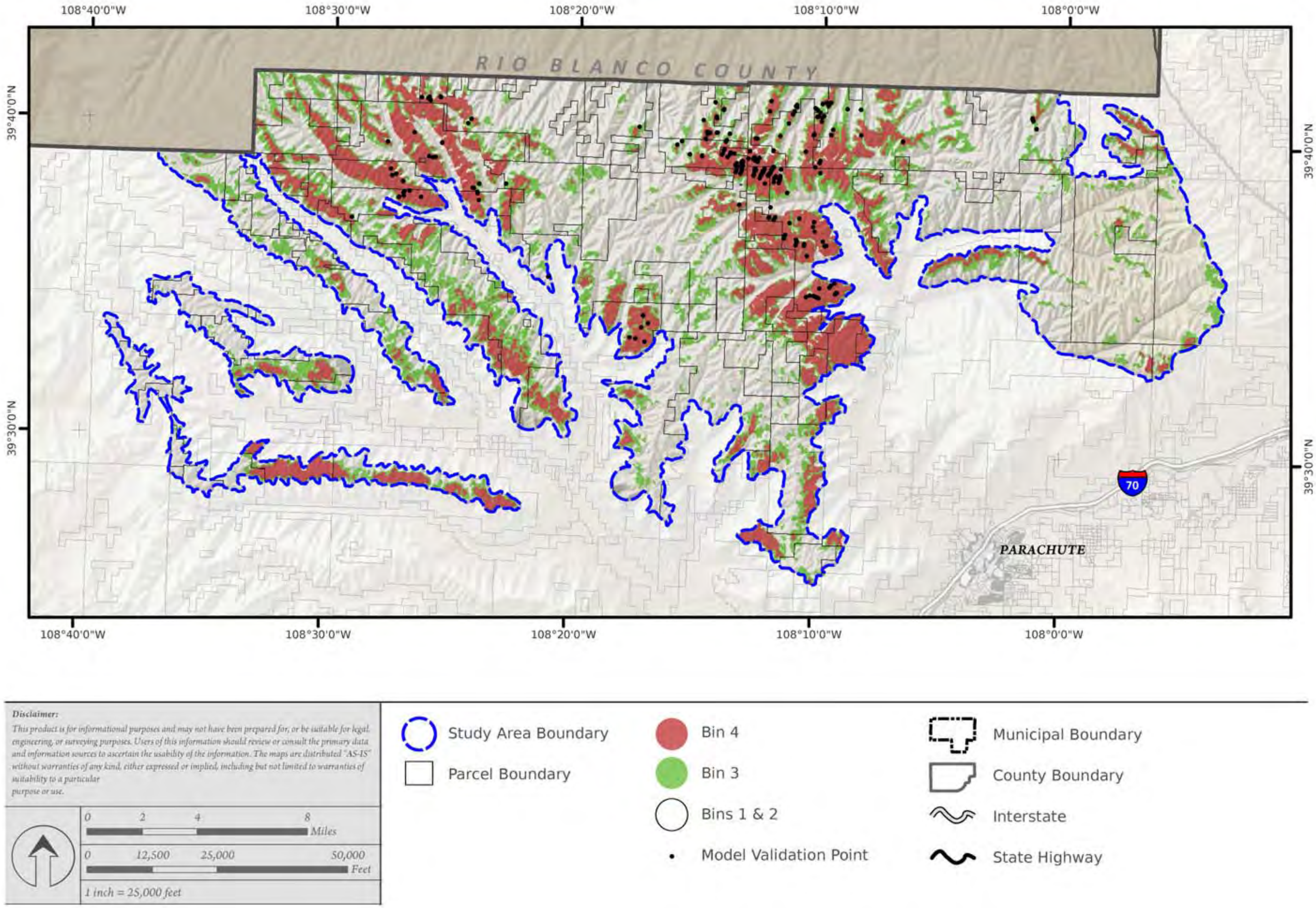
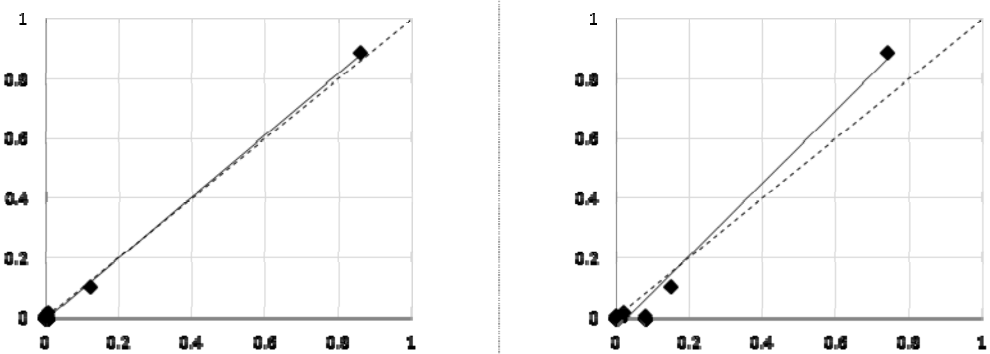


Figure 13: Fuzzy Validation Results: Expected vs. Observed Proportion of Presence Observations.



	Withheld Validation Set			CPW Lek Validation Set		
Regression	$y = 1.031x + 0.017$, Adj. r^2 **= 0.9987**			$y = 1.22x - 0.037$, Adj. r^2 **= 0.9805**		
Chi-square	χ^2	**Deg. Of Freedom**	ρ	χ^2	**Deg. Of Freedom**	ρ
	18	12	0.1157	24	16	0.0895
Spearman correlation	r^2	ρ		r^2	ρ	
	0.9852	0.0003		0.9412	0.005	

Model Assumptions and Limitations

Two primary subjects limit the predictive accuracy of the habitat models developed in this exercise; explanatory variables and uncertainties inherent to the sage-grouse signage points. Concerning explanatory variables, issues that may influence habitat selection beyond the scope of this analysis include 1) accuracy of the classified vegetation dataset, 2) omission of other potentially influential explanatory variables and 3) temporal discrepancies that exist between the signage points and explanatory variables. Regarding signage points, uncertainty exists in terms of understanding the full context of sage-grouse use and behavior at each signage location, as well as the limitation of not being able to discern seasonal use and occupation of an area.

As sage-grouse are a sagebrush obligate species, utilization of a vegetation dataset that accurately depicts vegetation communities and distribution of sagebrush is paramount to understanding habitat selection. Our decision to develop and utilize a vegetation dataset derived from classification of 1-m four-band aerial photography was motivated by the both the attribute and spatial inaccuracies inherent to both the CVCP (Colorado Vegetation Classification Project [CPW 2003]), and LANDFIRE (2010) vegetation datasets. Furthermore, the cell resolutions of each dataset, 25 m and 3 m respectively, are more applicable to development of a regional scale model, as opposed to the local scale model produced for this analysis.

While the results of the vegetation validation indicate an acceptable level of accuracy, only 45 of the 98 field validation locations were able to be field validated due to timing restrictions that prevented access to some private lands. For that reason, additional ocular assessments were performed by visually comparing the classified vegetation communities to underlying high-resolution photography (i.e., 30-cm cell resolution), as well as comparing the classified vegetation dataset results to other areas were data was verified in the field, including field-collected photographs and vegetation plot data. Following these secondary assessments, we were satisfied with the vegetation dataset produced from the image classification process and firmly believe it is the best available data to employ for habitat modeling for this location and scale of analysis. Nevertheless, a limited level of inaccuracy still exists in the data thereby influencing the predictive ability of the habitat models.

A second model limitation is the omission of other potentially influential explanatory variables, including anthropogenic factors and other resource-related criteria including canopy heights and densities, understory vegetation composition, soil types, wildfire risks and others. Anthropogenic variables (e.g., roads, well pads, compressors, pipeline corridors, water facilities, etc.) were excluded due to the lack of available data depicting these features and the inability to accurately produce data that adequately represented anthropogenic factors in a timely manner. Furthermore, recent literature reveals conflicting results on what types of anthropogenic factors and to what degree these features may impact habitat selection for the greater sage-grouse (Ramey, Brown and Blackgoat 2011). For example, a number of currently active and historical natural gas well pad sites exist across the PPR Study Area; based on photo interpretation, it is not evident in every case to determine which sites are active versus inactive. While an inactive pad site is still considered an anthropogenic impact, we know that some of historical pad sites in the PPR Study Area are used as lek locations (based on CPW lek count data). Due to the uncertainty in identifying anthropogenic factors in a timely manner, as well as the uncertainty in how they influence habitat selection, anthropogenic factors were excluded as an explanatory variable in this analysis.

Several other resource-related explanatory variables were omitted from this analysis as well, primarily due to the fact that literature and expert opinion do not indicate them to be primary indicators of habitat selection for sage-grouse, but also due to inadequate or inaccurate data sources. Data depicting canopy heights and densities are available for the project area from the LANDFIRE (2011) suite of data products, but review of the data revealed broad areas where the data did not accurately reflect on-the-ground conditions. Other omitted resource explanatory variables (e.g., soil types, livestock grazing pressure, climatic change) were excluded due to either their marginal influence in determining habitat selection or lack of data at the project level scale. While these variables are not considered to be key predictors of sage-grouse use and occupation, inclusion of these variables in the models would marginally strengthen the predictive ability of the habitat models.

The temporal discrepancies between the sage-grouse signage points and explanatory variables are an additional limitation of the habitat models. While we know the precise locations of when the signage points were collected, we do not know with certainty what the ground conditions were during the period that the bird was present at the location. The vegetation dataset we developed was produced from NAIP photography collected in 2012, therefore reflecting recent ground conditions. However, the collection of the signage points occurred from across a seven year period from 2005 – 2012. For that reason, uncertainty exists in accurately defining the conditions that existed at the precise point in time that the sage-grouse was present at the signage location.

Lastly, due to the inability to discern the duration of sage-grouse presence in a defined area, as well as the type of habitat use and behavior at each signage locations, the models are unable to classify seasonal habitats. In fact, the sage-grouse signage points are a collection of a data that most likely include indications of use across all seasons. Without knowing the precise time that the grouse were at the signage locations, it is not possible to predict seasonal use with these models.

Recognizing the limitations and uncertainties in the habitat models, we are satisfied with the predictive ability of the models as confirmed through significance in our model validation results, as well as concurrence with other similar models performed at similar scales within the PPR Study Area (Sauls et al. 2006, Walker et al. 2010). Future modeling efforts could be strengthened through inclusion of some of the omitted variables, as well as utilization of telemetry datasets that depicts marked bird locations at precise dates and times to generate a larger dataset of points for model training, including the ability to model and predict seasonal habitats.

DISCUSSION

RSF and fuzzy models utilizing field-collected sage-grouse data both accurately predicted use of habitats at local (100 m), intermediate (350 m) and landscape scales (1 km). These models were validated using randomly selected unique point features, which resulted in ranked bins accurately predicting frequencies of use. The RSF model validated with an R^2 value of 0.962. The top two bins predicted 97% occupancy while observed occupancy totaled 99% in bins 5 and 6, totaling 297 km^2 within the PPR Study Area. The RSF model was also validated against known lek locations, which also produced an R^2 value >0.98.

The fuzzy model utilized all sets of explanatory variables, without weighting, allowing a variable to exist in multiple bins at various degrees of membership. The results clearly showed that the fuzzy habitat model accurately validated against randomly selected sage-grouse location data and lek sites. The fuzzy model validated with an R^2 value of 0.999. The top two bins predicted 98% occupancy and observed occupancy totaled 98% in bins 3 and 4, totaling 295 km^2 within the PPR Study Area. In addition, the fuzzy model was validated against the independent dataset of known lek locations, with the model producing an R^2 value of 0.984 against lek locations.

MANAGEMENT IMPLICATIONS

We constructed two predictive models using distinctly different methods to assess sage-grouse habitat suitability within the PPR Study Area. The models demonstrate that of the 894-km^2 Study Area mapped as PPH and PGH by Rice et al. (2013), only 295-km^2 (34%) of the Study Area actually supported suitable sage-grouse habitats. Results suggest that a combination of both vegetation and topographic variables at multiple scales best explain habitat selection by sage-grouse in the PPR Study Area. The RSF model indicates a strong preference for sagebrush-dominated vegetation communities, while demonstrating negative associations with grassland, mixed mountain shrub and forested vegetation communities.

This is further supported by the vegetation selection index (Table 6), a generalized method of quantifying resource selection whereby the amount of a resource utilized is compared to resource availability; ratios producing a value greater than one indicate selection while ratios less than one indicate avoidance (Manly et al. 1992). The vegetation selection index indicates a selection rate of 54% for sagebrush-only and dominated landscapes, and 19% for sagebrush communities containing a marginal mixed mountain shrub component. Topographic variables indicate a negative association with slope and a positive association with a higher topographical position index (TPI), implying that local sage-grouse population prefer flatter areas on the top of ridgelines. These results are consistent with other previous and ongoing fine-scale modeling efforts conducted in the Study Area (Sauls et al. 2008; Walker et al. 2010) which indicate the PPR sage-grouse population select for sage-dominated vegetation communities that occur along ridge tops with shallow slopes. Sage-grouse preference of flatter terrain is also observed in other populations (Hupp and Braun 1989, Doherty et al. 2008) and can be an important habitat factor (Knick and Connelly 2011).

Table 6: Vegetation Selection Index

	Available		**Utilized**			
Vegetation Type	**Acres**	**%**	**Points**	**%**	**Selection Rate**	**Calibrated Selection Rate**
Bare	28,302.8	13%	287	24%	1.91	26%
Forest	33,992.1	15%	2	< 1%	0.01	< 1%
Grassland	19,611.1	9%	7	1%	0.07	1%
Mixed mountain shrub	69,614.7	31%	22	2%	0.06	1%
Riparian	70.9	< 1%	0	< 1%	0.00	< 1%
Sage dominant	59,995.1	27%	786	67%	4.01	54%
Sage/Mixed Mountain Shrub	9,496.0	4%	70	6%	1.39	19%

By contrast, the results of our two fine-scale predictive models differed dramatically from the Rice et al. (2013) sage-grouse mapping that delineates PPH and PGH habitats for the species within the PPR Study Area. The disparate results are likely explained by differences in 1) spatial resolution of the data employed in the model analyses and 2) explanatory variables employed in the models. Regarding spatial resolution, our models used raster data with 10 m cell resolution, similar to the Sauls et al. (2008) and Walker et al. (2010) models, as compared to the Rice et al. (2013) model that utilized raster data with a 1-kilometer cell resolution. The difference in cell resolution equates to a loss of information in the model results that are invaluable for local management policies and practices; for every possible single response in the Rice et al. (2013) model analyses, there were 10,000 possible responses in our model results.

Secondly, the Rice et al. (2013) model, once an area was known to be occupied sage-grouse, only considered vegetative explanatory variables, omitting significant topographical variables including slope, surface roughness and topographic or slope position. Particularly to the PPR Study Area, topographical variables are significant predictors of sage-grouse utilization; omission of these critical explanatory variables in assessing habitat suitability fails to recognize the diverse environment of the PPR Study Area, the limited areas of gentler terrain, and how the naturally fragmented landscape is selectively utilized by the local sage-grouse population.

While Rice et al. (2013) omitted the use of topographic variables in their models due to model scale, they recognized that localized studies indicate these factors strongly contribute to actual sage-grouse habitat utilization. Furthermore, Rice et al. (2013:8) did emphasize that "finer-scale and site-specific information…." should be used to identify priority areas for sage-grouse conservation. Our results support and quantify the conclusions of Rice et al. (2013) that finer-scale analysis is needed to adequately assess sage-grouse habitat suitability.

While the Rice et al. (2013) model analysis is not technically flawed, the dramatically broader spatial resolution of the data employed, combined with the omission of critical explanatory topographic variables, has the unintended consequence of over-predicting habitat by a three-fold factor in the PPR Study Area; the Rice et al. (2013) model results indicate the entirety of the Study Area is suitable sage-grouse habitat to some degree.

Gross over-prediction of habitats may not help support habitat management or species conservation, but rather may unnecessarily dilute conservation activities and priorities resulting in ineffective allocation of habitat improvement strategies. Preliminary Priority Habitat (PPH) is defined by the Sage-Grouse National Technical Team (NTT 2011:36) as "Areas that have been identified as having the highest conservation value to maintaining sustainable sage-grouse populations. These areas would include breeding, late brood-rearing, and winter concentration areas. These areas have been identified by state fish and wildlife agencies in coordination with respective BLM offices." Designated PPH and PGH habitats within the BLM's Draft RMPA and EIS have certain goals, objectives and management guidance associated for PPH and PGH areas. For example, the RMPA and EIS has: habitat restoration objectives to improve sagebrush habitats, wildfire management priorities, seasonal restrictions for fuels management activities, access restrictions, grazing restrictions, and other actions which may not actually benefit sage-grouse if PPH and PGH designations were erroneously applied to non-habitat. Goals and objectives tied to erroneously designated PPH and PGH areas could burden land management agencies with unnecessary management targets and "habitat improvement" targets in areas that were never, and will never actually be occupied by sage-grouse.

Additionally, applying erroneously mapped PPH and PGH designations on areas which do not support sage-grouse habitat may burden or restrict other land use activities; for example, the RMPA and EIS would impose a 3% surface disturbance cap on PPH and PGH areas, and even if the area is field-validated as being non-habitat, the validation process could be time consuming and burdensome for both land owners, land managers and regulatory agencies. When PPH and PGH areas may be over predicting habitat by approximately 60% in the PPR Study Area alone, this could impose significant burdens on landowners and land managers across very large areas.

With potential listing of the species under the Endangered Species Act, truly understanding and spatially depicting sage-grouse habitat could further inform policy and management of the species. Omission of critical explanatory data, or utilizing over-predicting habitat models could also lead managers to the conclusion that there is more available habitat than there truly is. The use of coarse models to map PPH and PGH attempts to predict important ("priority") habitats for sage-grouse conservation, yet as Rice et al. (2013:9) indicates "At the broad scale of these models, detecting specifics for individual birds or individual locations is not possible." We believe that even our models are still not accurate enough to detect specifics for "individual birds or individual locations", but the results presented by utilizing higher resolution vegetation data and more accurate modelling techniques still paints a much different picture of sage-grouse habitat suitability. While our model is not intended to drive regional policy, it presents additional information to help land use managers make more informed and hopefully more accurate and relevant decisions regarding management of sage-grouse habitats, and to help conservation efforts become more effective and meaningful at a scale and in locations that are more relevant to sage-grouse.

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APPENDIX A:

USING IMAGE CLASSIFICATION TO DEVELOP VEGETATION COVER TYPES

Introduction

Publicly available datasets depicting vegetation cover types across the project area were initially employed in the spatial models; the datasets include LANDFIRE vegetation cover (LANDFIRE 2011) and the Colorado Vegetation Classification Project (CVCP) (CPW 2003). However, review of the data revealed widespread inaccuracies in correctly identifying and classifying the vegetative cover types when compared to high-resolution aerial photography. In addition, the cell resolution of both the LANDFIRE and CVCP datasets, measured at 30 m^2 and 25 m^2 respectively, were too coarse to accurately delineate vegetation communities at the local scale. As a result, the spatial inaccuracies combined with the mistyped vegetative in both datasets led to our conclusion that the datasets were inadequate in appropriately identifying suitable vegetative cover types at the local scale.

In an effort to increase the accuracy of the spatial data depicting existing vegetative cover types within the Study Area, an image classification process involving color-infrared aerial photography was performed to better represent vegetation communities. Image classification is achieved by combining multiple bands from the same image to detect relative color, color intensity and texture to form clusters based on similar return values. Two major categories of image classification include supervised and unsupervised classification. Supervised classification is a method whereby the user defines training sites of known vegetation types within the analysis area; the training sites are subsequently used to as reference for classifying all other remaining pixels in the image into respective vegetation groups (Busch n.d.). By contrast, an unsupervised classification process relies on software analysis to identify and define similar pixel groups without user-defined training sites; the software uses a variety of statistical algorithms and techniques to identify related pixels and group them into similar classes (Busch, n.d.). Subsequently, the user assigns vegetation communities to the resulting classes using a combination of photo-interpretation and field-collected data.

Color-infrared photography provides four bands that detect specific wavelength ranges of reflected solar radiation; three bands within the visible light spectrum (e.g., red, green and blue), and a fourth near infrared band that measures reflected radiation beyond the visible light spectrum. The band combinations can yield a variety of properties and characteristics of the objects and vegetation interpreted in the aerial photography, including vegetation health, vegetation moisture and species identification (USDA 2008). For example, using the near infrared, red and green spectral bands to produce a ‘false color’ image (e.g., mapping the near infrared, red and green bands to RGB) provides high contrast between heavily vegetated areas (i.e., aspen, mixed conifer, and mixed mountain shrubs), less vegetated areas (grasslands, shrublands, etc.) and barren areas. Furthermore, within forested areas, image combinations utilizing the near infrared band help to distinguish between deciduous and coniferous tree species. Deciduous trees contain more chlorophyll and therefor reflect an intense bright red, while coniferous trees contain less chlorophyll and reflect lighter tones of red, magenta or pink. Within grassland and shrub communities, delineations were detected in a similar manner; the higher chlorophyll content in grasses and forbs caused these communities to reflect much brighter as compared to adjacent sagebrush communities.

Materials and Methods

The image classification for this project was performed on four-band 1-m^2 resolution photography acquired in 2011 from the USDA as part of the NAIP (USDA 2012) within the defined PPR Study Area. The NAIP imagery was re-sampled from 1-m^2, to 2-m^2 cell resolution to facilitate accurate grouping of similar vegetation classes by minimizing noise that results from mixed vegetation stands. The four-bands were subsequently combined using a number of techniques to yield band derivatives that distinguished and delineated presence of vegetation, amount of chlorophyll, band reflectance values and relative textures. The band derivatives were finally employed in an unsupervised image classification exercise to identify and delineate distinct vegetation communities within the PPR Study Area. Initially, the classification effort sought to identify the following vegetation cover types described in Table 1.

Table 1: Cover type classifications.

Cover Type	
Sagebrush	Gambel Oak
Sagebrush-dominated/grassland mix	Pinyon-Juniper
Sagebrush-dominated/mixed mountain shrub mix	Aspen
Grassland	Mixed conifer
Grass-dominated/mixed mountain shrub mix	Riparian
Mixed mountain shrubs	Bare surface

The primary intent of the classification exercise was to delineate both cohesive and mixed communities at a fine scale to study how they might influence habitat selection at the local scale. Secondarily, we hoped to distinguish oakbrush and pinyon-juniper dominated stands from mixed mountain shrubs, consisting primarily of snowberry, service berry and bitterbrush, to examine if one cover type exerted greater influence in habitat selection within the PPR Study Area.

Results and Discussion

The cover type map units were broadly defined and included several vegetation communities. The forested cover type included woodland areas dominated by aspen or conifers with mixed understories. The mixed mountain shrublands consisted of Utah serviceberry, mountain snowberry, bitterbrush and Gambel oak interspersed with grassland and herbaceous understories. The grasslands included bunchgrass meadows, allowing for encroachment of mixed mountain shrubs up to 25%. Sagebrush communities were dominated by a variety of sagebrush species, interspersed with bunchgrass and herbaceous understories. Both sagebrush-dominated/mixed mountain shrub and sagebrush-dominated/grassland mixed cover types contained a variety of sagebrush species intermixed with mixed mountain shrublands and bunchgrass meadows, with sagebrush cover ranging from 50% to 75%, respectively within these two cover types.

98 random points were generated across the project area for the purposes of field validation. Excluding bare surface and riparian cover types, each community was assigned 10 randomly generated points to inspect and confirm via field verification, with mixed conifer stands being assigned 8 randomly generated points for verification. Of the 98 potential points, only 45 were able to be field verified due to timing restrictions/limitations and limited access to some private lands.

The initial image classification exercise attempted to distinguish Gambel oak and pinyon-juniper from the broader mixed mountain shrublands cover type. In addition, aspen stands were classified separately from mixed conifer stands. The initial classification effort correctly identified 31 of the 45 of the randomly sampled field plots. Results of the initial classification effort are provided in Table 2.

Table 2: Accuracy assessment of initial image classification.

Cover Type	# Correct	Total Plots	% Correct
Aspen	7	7	100%
Gamble Oak	2	3	67%
Grasslands	1	3	33%
Grassland/mixed mountain shrubs	0	6	0%
Mixed Conifer	7	7	100%
Mixed mountain shrubs	4	5	80%
Pinyon-juniper	0	4	0%
Sagebrush	3	3	100%
Sagebrush-dominated/grass	3	3	100%
Sagebrush-dominated/mixed mountain shrubs	4	4	100%
Total	**31**	**45**	**68%**

The validation of the initial classification effort resulted in a total of 68% of the field plots being correctly identified which falls below the acceptable interpretation accuracy of 85% (Anderson et al. 1976). While several communities validated with 100% accuracy, the low predictive accuracy for Gambel oak, pinyon-juniper, grasslands and grassland/mixed mountain shrubs cover types hampered the accuracy of the overall classified dataset.

Field validation revealed that map units typed as pinyon-juniper cover type were, in fact, mixed mountain shrubland communities. Consequently, the pinyon-juniper mapped units were converted to mixed mountain shrubland communities. Likewise, while two of the three Gambel oak sample plots were correctly verified, they nevertheless contained a high percentage of mixed mountain shrublands; the third sample plot was field verified as mixed mountain shrublands. As such, the Gambel oak map units were also converted to mixed mountain shrublands, based on limitations in the model accurately distinguishing between Gambel oak and other mixed mountain shrub species.

In addition, the poor predictive accuracy of grassland and grassland/mixed mountain shrub communities warranted a second review of the data. Of the six field plots for grass/mixed mountain shrub cover types, none were accurately verified. Rather five of the six sample plots revealed a much higher percentage of shrubs, while the sixth plot was verified as sagebrush. Furthermore, only one of the three grassland field sample plots was correctly verified; the remaining two plots were identified as sagebrush communities. Subsequently, the units originally mapped as either grasslands or grass/mixed mountain shrub cover types were re-analyzed and re-typed as either grassland, mixed mountain shrublands or sagebrush. Lastly, both aspen and mixed conifer cover types were combined to form a single forested cover type.

The revised classified dataset was re-validated using the original 45 field verified sample plots. The secondary validation effort against the revised dataset correctly identified 41 of the 45 randomly sampled field plots. Results of the revised vegetation classification accuracy assessment are presented in Table 3.

Table 3: Accuracy assessment of final image classification.

Cover Type	# Correct	Total Plots	% Correct
Grassland	1	3	33%
Forested	14	14	100%
Mixed mountain shrubs	16	18	89%
Sagebrush	3	3	100%
Sagebrush-dominated/grass	3	3	100%
Sagebrush-dominated/mixed mountain shrubs	4	4	100%
Total	**31**	**45**	**87%**

The second validation of the revised classification effort resulted in a total of 87% of the field plots being correctly identified, indicating the dataset meets acceptable interpretation accuracy. Overall, most mapped communities validated exceptionally well, excluding grassland communities which still had a low predictive accuracy of 33%, and to a lesser degree, mixed mountain shrubland cover types. An error matrix for the mapped cover types are presented in the Table 4.

Table 4: Error matrix for final mapped cover types.

Mapped Cover Type	Actual Cover Type					
	Grassland	Forested	Mixed mountain shrubs	Sagebrush	Sage-dominated/grass	Sage-dominated/mixed mountain shrubs
Grassland	1			2		
Forested		14				
Mixed mountain shrubs		1	16	1		
Sagebrush				3		
Sagebrush-dominated/grass					3	
Sagebrush-dominated/mixed mountain shrubs						4
Total	**1**	**15**	**16**	**6**	**3**	**4**

Overall, the final classified cover type dataset resulted in seven distinct cover types within the PPR Study Area. The results of the classification are quantified in Table 5.

Table 5: Final image classification cover types quantified.

Cover Type	Acres	% of Study Area
Bare	28,303	13%
Grassland	19,611	9%
Forested	33,992	15%
Mixed mountain shrubs	69,615	31%
Riparian	71	< 1%
Sagebrush	38,240	17%
Sagebrush-dominated/grass	21,756	10%
Sagebrush-dominated/mixed mountain shrubs	9,496	4%
Total	**221,084**	**100%**

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Appendix B
Vegetation Classification Model Validation Point Data

The following section presents the vegetation data points initially installed to help refine the initial vegetation classification model. Based on the results of these data plots, the model was revised and re-run to more accurately document vegetation conditions in the PPR.

Access was generously provided Oldland Ranch, Oxy (USA) Inc., Chevron North America Exploration and Production, and Encana Oil & Gas (USA), Inc. BLM lands were also utilized as part of this effort.

Aspen Points

AS_01

North View: Photo file: AS_01.jpg

East View: Photo file: AS_01e.jpg

South View: Photo file: AS_01s.jpg

West View: Photo file: AS_01w.jpg

Plot ID: AS-01
Survey Date: September 26, 2013
Cover Type: Aspen
Sage Cover: 0%
Other Shrub Cover: *Populus tremuloides* 85%, *Symphoicarpos oreophilus* 45%, *Amelanchier alnifolia* 15%, *Prunus virginiana* 7%
Total Shrub Cover: 65%
Grass Cover: 70%
Forb Cover: 20%
Aspect: northeast
Slope: 17°
Insect/Disease: some *Populus tremuloides* decline.
Dominant Plant Species: *Bromus anomalus*, *Elymus spp.*, *Rosa woodsii*, *Carex geyeri*, *Aquilegia caerulea*, *Ozmorhizza spp.*

Notes: Overstory is mostly dead, but good understory regen.

AS_03

Photo file: AS_03n.jpg

Photo file: AS_03e.jpg

Photo file: AS_03s.jpg

Photo file: AS_03w.jpg

Plot ID: AS-03
Survey Date: August 30, 2013
Cover Type: Aspen
Sage Cover: 0%
Other Shrub Cover: *Symphoricarpos oreophilus* 55%, *Populus tremuloides* 15%, *Rosa woodsii* 7%
Total Shrub Cover: 65%
Grass Cover: 50%
Forb Cover: 15%
Aspect: north
Slope: 13°
Insect/Disease: some aspen decline

Dominant Plant Species: *Populus tremuloides*, *Symphoricarpos oreophilus*, *Pedicularis bracteosa*, *Viscia americana*, *Mentha arvensis*

Notes:

AS_06

Photo file: AS_06n.jpg

Photo file: AS_06e.jpg

Photo file: AS_06s.jpg

Photo file: AS_06w.jpg

Plot ID: AS-06
Survey Date: September 15, 2013
Cover Type: Aspen
Sage Cover: 0%
Other Shrub Cover: *Symphoricarpos oreophilus* 45%, *Populus tremuloides* 40%, *Rosa woodsii* 2%, *Ribes cereum* 1%, *Acer glabrum* 2%, *Prunus virginiana* 2%, *Amelanchier alnifolia* 8%
Total Shrub Cover: 60%
Grass Cover: 20%
Forb Cover: 18%
Aspect: southwest
Slope: 30°
Insect/Disease: Approximately 50% of *Populus tremuloides* are standing dead

Dominant Plant Species: *Populus tremuloides*, *Symphoricarpos oreophilus*, *Thalictrum fendleri*, *Geranium viscosissimum*, *Viscia americana*, *Cynoglossum officinalis*

Notes:

AS_07

Photo file: AS_07n.jpg

Photo file: AS_07e.jpg

Photo file: AS_07s.jpg

Photo file: AS_07w.jpg

Plot ID: AS-07
Survey Date: August 30, 2013
Cover Type: Aspen
Sage Cover: 0%
Other Shrub Cover: *Symphoricarpos oreophilus* 20%, *Populus tremuloides* 30%
Total Shrub Cover: 20%
Grass Cover: 30%
Forb Cover: 50%
Aspect: east
Slope: 20°
Insect/Disease:

Dominant Plant Species: *Populus tremuloides*, *Symphoricarpos oreophilus*, *Thalictrum fendleri*, *Mentha arvensis*, elytra, *Poa pratensis*, *Senecio serra*, *Viscia americana*, *Carex geyeri*, *Lupinus spp.*

Notes:

AS_08

Photo file: AS_08n.jpg

Photo file: AS_08e.jpg

Photo file: AS_08s.jpg

Photo file: AS_08w.jpg

Plot ID: AS_08
Survey Date: September 25, 2013
Cover Type: Aspen
Sage Cover: 0%
Other Shrub Cover: *Populus tremuloides* 17%, *Symphoicarpos oreophilus* 58%, *Quercus gambelii* 2%, *Amelanchier utahensis* 2%, *Prunus virginiana* 3%
Total Shrub Cover: 65%
Grass Cover: 70%
Forb Cover: 10%
Aspect: east
Slope: 22°
Insect/Disease: *Populus tremuloides* is pretty decadent

Dominant Plant Species: *Populus tremuloides*, *Carex geyeri*, *Poa pratensis*, *Conioselinum scopulorum*, *Gallium spp.*, *Viscia americana*, *Mentha arvensis*

Notes:

AS_09

Photo file: AS_09n.jpg

Photo file: AS_09e.jpg

Photo file: AS_09s.jpg

Photo file: AS_09w.jpg

Plot ID: AS-09
Survey Date: August 30, 2013
Cover Type: Aspen
Sage Cover: 0%
Other Shrub Cover: *Amelanchier alnifolia* 15%, *Prunus virginiana* 30%, *Symphoricarpos oreophilus* 18%
Total Shrub Cover: 65%
Grass Cover: 45%
Forb Cover: 16%
Aspect: north
Slope: 15°
Insect/Disease: larger *Populus tremuloides* are mostly dead, some regeneration

Dominant Plant Species: *Populus tremuloides*, *Amelanchier alnifolia*, *Prunus virginiana*, *Symphoricarpos oreophilus*, *Carex geyeri*, *Bromus anomalus*, *Gallium spp.*, *Mentha arvensis*, *Viscia americana*, *Ozmorhizza spp.i*, *Potentilla pulcherrima*, *Rosa woodsii*, *Poa pratensis*.

Notes: quite a bit of bear sign

AS_10

Photo file: AS_10n.jpg

Photo file: AS_10e.jpg

Photo file: AS_10s.jpg

Photo file: AS_10w.jpg

Plot ID: AS_10
Survey Date: September 26, 2013
Cover Type: Aspen
Sage Cover: 0%
Other Shrub Cover: *Populus tremuloides* 78%, *Symphoricarpos oreophilus* 45%, *Amelanchier alnifolia* 14%, *Rosa woodsii* 4%
Total Shrub Cover: 50%
Grass Cover: 65%
Forb Cover: 19%
Aspect: north
Slope: 27°
Insect/Disease: low levels of *Populus tremuloides* decline

Dominant Plant Species: *Geranium viscossissimum*, *Bromus anomalus*, *Elymus spp.*, *Pedicularis bracteosa*, *Ozmorhizza spp.*

Notes:

Gambel Oak Points

GO_07

Photo file: GO_07n.jpg

Photo file: GO_07e.jpg

Photo file: GO_07s.jpg

Photo file: GO_07w.jpg

Plot ID: GO_07
Survey Date: September 25, 2013
Cover Type:
Sage Cover: 10%
Other Shrub Cover: *Amelanchier utahensis* 30%, *Artemisia tridentata* 10%, *Symphoicarpos oreophilus* 5%, *Chrysothamnus viscosissimum* 2%
Total Shrub Cover: 47%
Grass Cover: 14%
Forb Cover: 7%
Aspect:
Slope: 16°
Insect/Disease:

Dominant Plant Species: *Eriogonum umbellatum*, *Castilleja* spp., *Mahonia repens*, *Carex geyeri*, *Pseudoroegneria spicata*, *Poa pratensis*, *Carex geophila*

Notes:

GO_09

Photo file: GO_09n.jpg

Photo file: GO_09e.jpg

Photo file: GO_09s.jpg

Photo file: GO_09w.jpg

Plot ID: GO_09

Survey Date: September 2, 2013

Cover Type: mixed mountain shrublands

Sage Cover: 0%

Other Shrub Cover: *Amelanchier utahensis* 80%, *Prunus virginiana* 5%, *Symphoicarpos oreophilus* 20%, *Quercus gambelii* 2%

Total Shrub Cover: 85%

Grass Cover: 10%

Forb Cover: 8%

Aspect:

Slope: 42°

Insect/Disease:

Dominant Plant Species: *Carex geyeri*, *Mahonia repens*

Notes:

GO_10


Photo file: GO_10n.jpg


Photo file: GO_10e.jpg

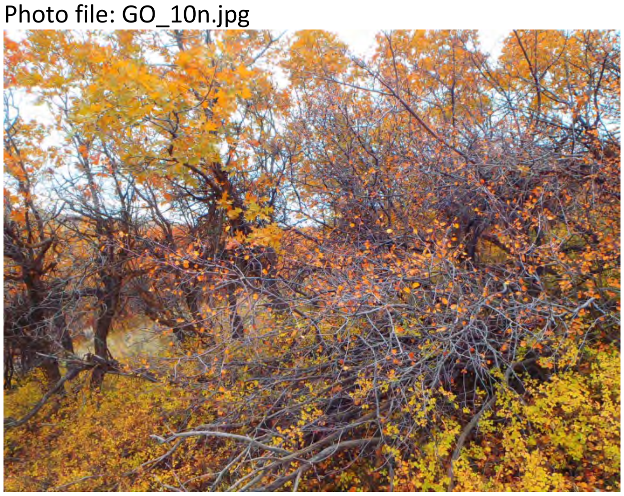
Photo file: GO_10s.jpg


Photo file: GO_10w.jpg

Plot ID: GO_10
Survey Date: October 9, 2013
Cover Type:
Sage Cover: 1%
Other Shrub Cover: *Amelanchier utahensis* 10%, *Quercus gambelii* 15%, *Symphoicarpos oreophilus* 60%, *Artemisia tridentata* 1%
Total Shrub Cover: 50%
Grass Cover: 75%
Forb Cover:
Aspect: East
Slope: 18°
Insect/Disease:

Dominant Plant Species:

Notes:

Grass Points

GR_06

Photo file: GR_06n.jpg

Photo file: GR_06e.jpg

Photo file: GR_06s.jpg

Photo file: GR_06w.jpg

Plot ID: GR_06
Survey Date: October 8, 2013
Cover Type: sagebrush
Sage Cover: 20%
Other Shrub Cover: *Symphoicarpos oreophilus* 40%, *Chrysothamnus viscosissimum* 10%, *Artemisia tridentata* 20%, *Amelanchier utahensis* 2%
Total Shrub Cover: 80%
Grass Cover: 70%
Forb Cover: 20%
Aspect: southwest
Slope: 4°
Insect/Disease:

Dominant Plant Species: *Carex geyeri*, *Poa secunda*, *Lupinus spp.*, *Balsamorhiza sagittata*

Notes:

GR_08

Photo file: GR_08n.jpg

Photo file: GR_08e.jpg

Photo file: GR_08s.jpg

Photo file: GR_08w.jpg

Plot ID: GR_08
Survey Date: September 2, 2013
Cover Type: *Symphorocarpos oreophilus*berry/*Populus tremuloides*
Sage Cover: 0%
Other Shrub Cover: *Symphoricarpos oreophilus* 80%
Total Shrub Cover: 80%
Grass Cover: 40%
Forb Cover: 5%
Aspect: southwest
Slope: 4°
Insect/Disease: *Populus tremuloides* fading…

Dominant Plant Species: *Populus tremuloides*, *Symphoricarpos oreophilus*, elytra, *Poa secunda*, *Pascopyrum smithii*, *Achillea millefolia*, *Lupinus spp*., *Pseudoroegneria spicata*.

Notes:

GR_10

Photo file: GR_10n.jpg

Photo file: GR_10e.jpg

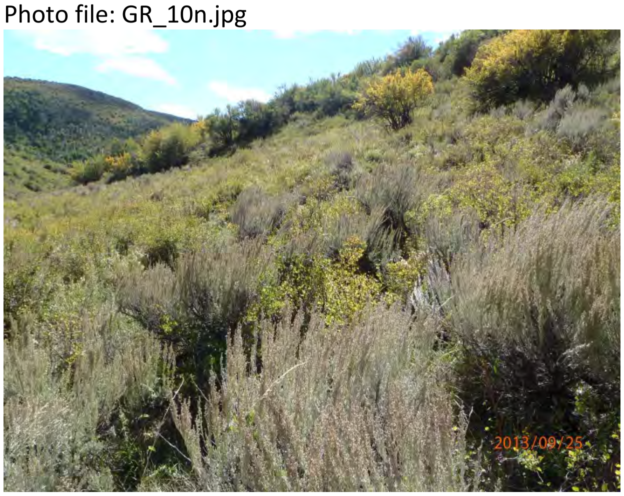

Photo file: GR_10s.jpg

Photo file: GR_10w.jpg

Plot ID: GR_10
Survey Date: September 25, 2013
Cover Type: sagebrush
Sage Cover: 10%
Other Shrub Cover: *Artemisia tridentata* 10%, *Symphoricarpos oreophilus* 15%, *Chrysothamnus viscosissimum* 5%, *Oligosporus pacificus* 7%
Total Shrub Cover: 50%
Grass Cover: 20%
Forb Cover: 5%
Aspect:
Slope: 7°
Insect/Disease:

Dominant Plant Species: *Leymus cinereus*, *Poa pratensis*, *Lappula occidentalis*, *Viscia americana*, *Lupinus spp.*, *Penstemon strictus*

Notes:

Grass- Mixed Mountain Shrub Points

GM_01

Photo file: GM_01n.jpg

Photo file: GM_01e.jpg

Photo file: GM_01s.jpg

Photo file: GM_01w.jpg

Plot ID: GM_01
Survey Date: September 2, 2013
Cover Type: Mixed mountain shrub
Sage Cover: 0%
Other Shrub Cover: *Amelanchier utahensis* 25%, *Quercus gambelii* 30%, *Prunus virginiana* 1%, *Symphoricarpos oreophilus* 3%
Total Shrub Cover: 60%
Grass Cover: 30%
Forb Cover: 6%
Aspect: southwest
Slope: 20°
Insect/Disease:

Dominant Plant Species: *Quercus gambelii*, *Prunus virginiana*, *Amelanchier alnifolia*, *Symphoricarpos oreophilus*, *Carex geyeri*, *Aster* spp.

Notes:

GM_03

Photo file: GM_03n.jpg

Not Available

Photo file: GM_03e.jpg

Photo file: GM_03s.jpg

Photo file: GM_03w.jpg

Plot ID: GM_3

Survey Date: September 25, 2013

Cover Type: sagebrush

Sage Cover: 16%

Other Shrub Cover: *Amelanchier utahensis* 4%, *Artemisia tridentata* 16%, *Symphoicarpos oreophilus* 28%

Total Shrub Cover: 60%

Grass Cover: 24%

Forb Cover: 14%

Aspect:

Slope: 15°

Insect/Disease:

Dominant Plant Species: *Bromus inermis*, *Elymus cinereus*, *Carex geyeri*, pisipi, *Poa pratensis*, *Gallium spp.*, *Chrysothamnus viscosissimum*, *Lupinus spp.*, *Penstemon strictus*, *Eriogonum umbellatum*, *Helenium autumnale*

Notes:

GM_04

Photo file: GM_04n.jpg

Photo file: GM_04e.jpg

Photo file: GM_04s.jpg

Photo file: GM_04w.jpg

Plot ID: GM_04
Survey Date: October 8, 2013
Cover Type: Mixed mountain shrub
Sage Cover: 0%
Other Shrub Cover: *Populus tremuloides* 15%, *Amelanchier utahensis* 10%, *Prunus virginiana* 2%, *Symphoicarpos oreophilus* 60%, *Quercus gambelii* 2%
Total Shrub Cover: 80%
Grass Cover: 75%
Forb Cover: 10%
Aspect:
Slope: 25°
Insect/Disease:

Dominant Plant Species: *Carex geyeri*, *Poa pratensis*, *Gallium spp.*, *Achillea millefolia*, thistle, *Chenopodium leptophyllum*, *Mentha arvensis*

Notes:

GM_06

Photo file: GM_06n.jpg

Photo file: GM_06e.jpg

Photo file: GM_06s.jpg

Photo file: GM_06w.jpg

Plot ID: GM_06
Survey Date: October 8, 2013
Cover Type: *Populus tremuloides*/shrub
Sage Cover: 0%
Other Shrub Cover: *Amelanchier utahensis* 40%, *Populus tremuloides* 20%, *Symphorocarpos oreophilus* 65%
Total Shrub Cover: 80%
Grass Cover: 30%
Forb Cover: 10%
Aspect: east
Slope: 33°
Insect/Disease:

Dominant Plant Species: *Carex geyeri*, *Poa fendleri*

Notes:

GM_08

Photo file: GM_08n.jpg

Photo file: GM_08e.jpg

Photo file: GM_08s.jpg

Photo file: GM_08w.jpg

Plot ID: GM_08
Survey Date: September 25, 2013
Cover Type: Mixed mountain shrub
Sage Cover: 4%
Other Shrub Cover: *Amelanchier utahensis* 8%, *Quercus gambelii* 23%, *Prunus virginiana* 1%, *Symphoicarpos oreophilus* 20%, *Artemisia tridentata* 4%,
Total Shrub Cover: 58%
Grass Cover: 20%
Forb Cover: 10%
Aspect: southeast
Slope: 20°
Insect/Disease:

Dominant Plant Species: *Carex geyeri*, *Poa pratensis*, *Pseudoroegneria spicata*, *Galium triflorum*, *Achillea millefolia*, *Aster* spp., *Collinsia parviflora*

Notes:

GM_09

Photo file: GM_09n.jpg

Photo file: GM_09e.jpg

Photo file: GM_09s.jpg

Photo file: GM_09w.jpg

Plot ID: GM_09
Survey Date: September 25, 2013
Cover Type: Mixed mountain shrub
Sage Cover: 4%
Other Shrub Cover: *Amelanchier utahensis* 2%, *Quercus gambelii* 34%, *Symphoricarpos oreophilus* 28%, *Artemisia tridentata* 4%, *Chrysothamnus viscosissimum* 15%,
Total Shrub Cover: 70%
Grass Cover: 28%
Forb Cover: 15%
Aspect: southwest
Slope: 17°
Insect/Disease:

Dominant Plant Species: *Helenium autumnale*, *Carex geyeri*, *Ozmorhizza spp.i*, *Poa pratensis*, *Gallium spp.*, *Pseudoroegneria spicata*, *Balsamorhiza sagittata*, *Wyethia amplexicaulis*

Notes:

Mixed Conifer Points

MC_01

Photo file: MC_01n.jpg

Photo file: MC_01e.jpg

Photo file: MC_01s.jpg

Photo file: MC_01w.jpg

Plot ID: MC_01
Survey Date: September 2, 2013
Cover Type: Mixed conifer
Sage Cover: 0%
Other Shrub Cover: *Amelanchier alnifolia* 3%, *Symphoricarpos oreophilus* 28%, Douglas-fir 5%
Total Shrub Cover: 30%
Grass Cover: 70%
Forb Cover: 15%
Aspect: northwest
Slope: 30°
Insect/Disease: 80% of Douglas-fir dead

Dominant Plant Species: *Pseudotsuga menziesii*, *Amelanchier alnifolia*, *Symphoricarpos oreophilus*, *Ozmorhizza spp.i*, *Carex geyeri*, *Gallium spp.*, *Elymus trachycaulis*, *Corydalis aurea*, *Bromus anomalus*, *Bromus marginatus*, *Stipa purpurea*, *Cynoglossum officinalis*

Notes:

MC_02

Photo file: MC_02n.jpg

Photo file: MC_02e.jpg

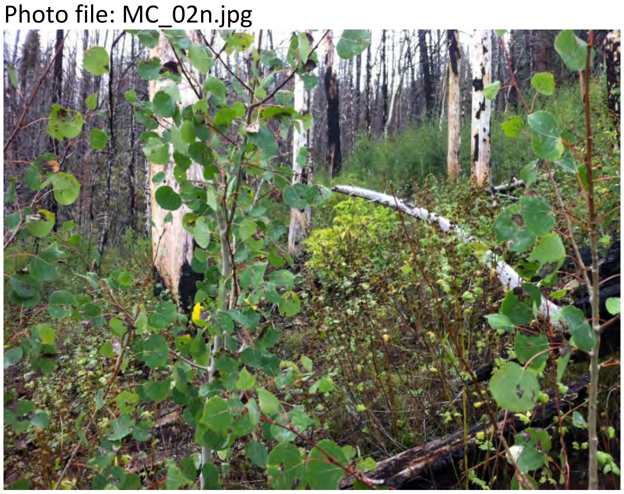

Photo file: MC_02s.jpg

Photo file: MC_02w.jpg

Plot ID: MC_02
Survey Date: September 15, 2013
Cover Type: Mixed conifer
Sage Cover: 0%
Other Shrub Cover: *Sambucus racemosa* 1%, *Symphoricarpos oreophilus* 1%, *Populus tremuloides* 30%
Total Shrub Cover: 2%
Tree Cover: 30%
Grass Cover: 5%
Forb Cover: 35%
Aspect: northeast
Slope: 20°
Insect/Disease:
Dominant Plant Species: *Cynoglossum officinalis*, *Carex geyeri*, *Geranium* spp., *Gallium spp.*, *Chenopodium leptophyllum*, *Sambucus racemosa*

Notes: In an old burn, mostly all *Populus tremuloides* regeneration. Few spruce on the edge of burn at the top

MC_03


Photo file: MC_03n.jpg


Photo file: MC_03e.jpg


Photo file: MC_03s.jpg


Photo file: MC_03w.jpg

Plot ID: MC_03
Survey Date: September 15, 2013
Cover Type: Mixed conifer
Sage Cover: 0%
Other Shrub Cover: *Ribes cereum* 20%, *Prunus virginiana* 5%, *Acer glabrum* 1% *Amelanchier alnifolia* 1%, *Symphoricarpos oreophilus* 1%, *Rosa woodsii* 1%, *Pseudotsuga menziesii* 55%, *Populus tremuloides* 5%
Total Shrub Cover: 40%
Tree Cover: 60%
Grass Cover: 3%
Forb Cover: 2%
Aspect: northwest
Slope: 23°
Insect/Disease: Lots of down fall and very few standing dead

Dominant Plant Species: *Pseudotsuga menziesii*, *Amelanchier alnifolia*, *Symphoricarpos oreophilus*, *Carex geyeri*, *Thalictrum fendleri*
Notes:

MC_04

Photo file: MC_04n.jpg

Photo file: MC_04e.jpg

Photo file: MC_04s.jpg

Photo file: MC_04w.jpg

Plot ID: MC_04
Survey Date: September 15, 2013
Cover Type: Mixed conifer
Sage Cover: 0%
Other Shrub Cover: *Amelanchier alnifolia* 7%, *Symphoricarpos oreophilus* 45%, *Acer glabrum* 2%, *Populus tremuloides* 5%, Douglas-fir 28%
Total Shrub Cover: 55%
Tree Cover: 30%
Grass Cover: 27%
Forb Cover: 4%
Aspect: south
Slope: 23°
Insect/Disease: Some standing dead *Populus tremuloides*

Dominant Plant Species: *Pseudotsuga menziesii*, *Amelanchier alnifolia*, *Symphoricarpos oreophilus*, *Carex geyeri*, *Arctostaphylos uva-ursi*, *Cynoglossum officinalis*, *Mahonia repens*

Notes:

MC_05

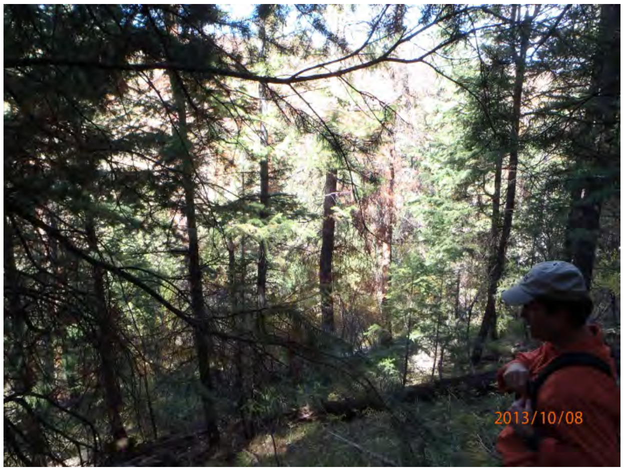

Photo file: MC_05n.jpg

Photo file: MC_05e.jpg

Photo file: MC_05s.jpg

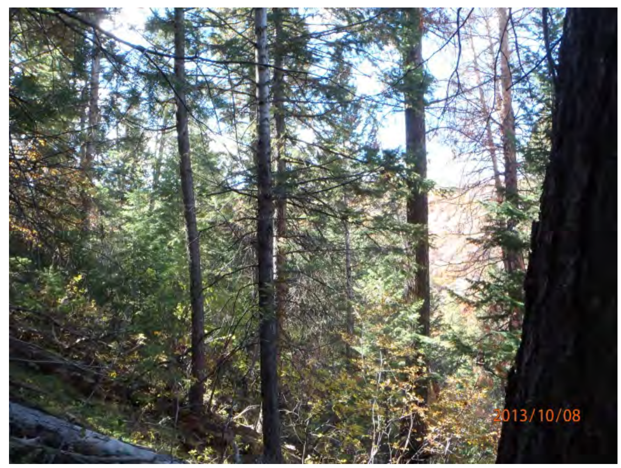

Photo file: MC_05w.jpg

Plot ID: MC_05
Survey Date: October 8, 2013
Cover Type: Mixed conifer
Sage Cover: 0%
Other Shrub Cover: *Pseudotsuga menziesii* 85%, *Amelanchier utahensis* 10%, *Symphorocarpos oreophilus* 6%,
Total Shrub Cover: 15%
Tree Cover: 85%
Grass Cover: 75%
Forb Cover: 10%
Aspect: northwest
Slope: 42°
Insect/Disease: Lots of down fall and very few standing dead

Dominant Plant Species:

Notes:

MC_07

Photo file: MC_07n.jpg

Photo file: MC_07e.jpg

Photo file: MC_07s.jpg

Photo file: MC_07w.jpg

Plot ID: MC_07
Survey Date: September 15, 2013
Cover Type: Mixed conifer
Sage Cover: 0%
Other Shrub Cover: *Rubus idaeus* 8%, *Symphoricarpos oreophilus* 1%, *Abies bifolia* 40%, *Pseudotsuga menziesii* 15%, *Populus tremuloides* 3%
Total Shrub Cover: 9%
Tree Cover: 50 %
Grass Cover: 15%
Forb Cover: 5%
Aspect: north
Slope: 23°
Insect/Disease:

Dominant Plant Species: *Pseudotsuga menziesii*, *Amelanchier alnifolia*, *Symphoricarpos oreophilus*, *Carex geyeri*, *Gallium spp.*, *Thalictrum fendleri*, *Rosa woodsii*, *Geranium viscossissimum*

Notes:

MC_08

Photo file: MC_08n.jpg

Photo file: MC_08e.jpg

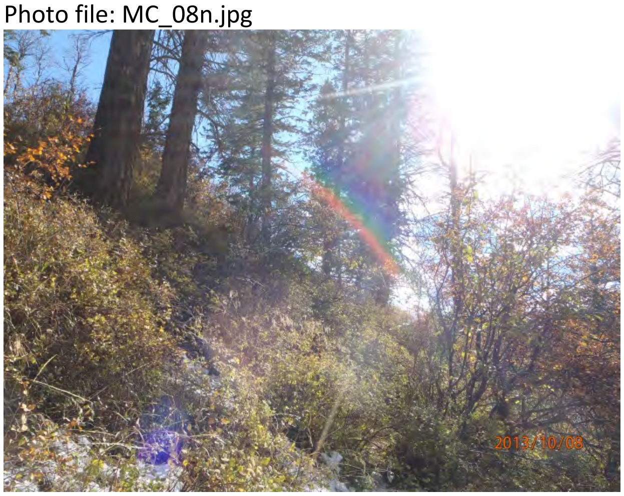

Photo file: MC_08s.jpg

Photo file: MC_08w.jpg

Plot ID: MC_08
Survey Date: October 8, 2013
Cover Type: Mixed conifer
Sage Cover: 0%
Other Shrub Cover: *Pseudotsuga menziesii* 15% (60% is dead), *Acer glabrum* 1%, *Amelanchier utahensis* 8%, *Symphoicarpos oreophilus* 60%
Total Shrub Cover: 70%
Tree Cover: 15 %
Grass Cover: 80%
Forb Cover: 10%
Aspect: west
Slope: 41°
Insect/Disease:

Dominant Plant Species: *Carex geyeri*, *Bromus anomalus*, *Elymus glaucus*, *Chenopodium leptophyllum*, *Gallium spp.*

Notes:

Mixed Mountain Shrub Points

MM_05

Photo file: MM_05n.jpg

Photo file: MM_05e.jpg

Photo file: MM_05s.jpg

Photo file: MM_05w.jpg

Plot ID: MM_05

Survey Date: September 25, 2013

Cover Type: Mixed mountain shrub

Sage Cover: 20%

Other Shrub Cover: *Amelanchier utahensis* 28%, *Symphoicarpos oreophilus* 10%, *Artemisia tridentata* 20%, *Chrysothamnus viscosissimum* 4%

Total Shrub Cover: 65%

Grass Cover: 12%

Forb Cover: 6%

Aspect:

Slope: 22°

Insect/Disease:

Dominant Plant Species: *Eriogonum umbellatum*, *Carex geyeri*, *Gallium spp.*, *Pascopyrum smithii*, *Lupinus spp.*, *Penstemon strictus*, *Castillaja* spp.

Notes:

MM_07

Photo file: MM_07n.jpg

Photo file: MM_07e.jpg

Photo file: MM_07s.jpg

Photo file: MM_07w.jpg

Plot ID: MM_07
Survey Date: September 25, 2013
Cover Type: Mixed mountain shrub
Sage Cover: 18%
Other Shrub Cover: *Amelanchier utahensis* 20%, *Artemisia tridentata* 18%, *Chrysothamnus viscosissimum* 8%, *Symphoicarpos oreophilus* 6%
Total Shrub Cover: 65%
Grass Cover: 15%
Forb Cover: 9%
Aspect: east
Slope: 22°
Insect/Disease:

Dominant Plant Species: *Pascopyrum smithii*, *Poa pratensis*, *Carex geyeri*, *Eriogonum umbellatum*, *Viscia americana*, *Lupinus spp.*, *Heterotheca villosa*, *Castilleja* spp., *Penstemon procerus*

Notes:

MM_08

Photo file: MM_08n.jpg

Photo file: MM_08e.jpg

Photo file: MM_08s.jpg

Photo file: MM_08w.jpg

Plot ID: MM_08
Survey Date: September 2, 2013
Cover Type: Mixed mountain shrub
Sage Cover: 3%
Other Shrub Cover: *Amelanchier utahensis* 30%, *Purshia tridentata* 6%, *Symphoricarpos oreophilus* 4%
Total Shrub Cover: 40%
Grass Cover: 6%
Forb Cover: 5%
Aspect: southwest
Slope: 20°
Insect/Disease:

Dominant Plant Species: *Amelanchier utahensis*, *Purshia tridentata*, *Symphoricarpos oreophilus*, *Artemisia tridentata*, *Chrysothamnus viscosissimum*, *Eriogonum umbellatum*, *Lupinus spp*., *Carex geyeri*, *Quercus gambelii*, *Oryzopsis hymenoides*, *Viscia americana*

Notes:

MM_09

Photo file: MM_09n.jpg

Photo file: MM_09e.jpg

Photo file: MM_09s.jpg

Photo file: MM_09w.jpg

Plot ID: MM_09
Survey Date: October 8, 2013
Cover Type: Mixed conifer
Sage Cover: 0%
Other Shrub Cover: *Pseudotsuga menziesii* 90%, *Populus tremuloides* 5%, *Amelanchier alnifolia* 10%, *Rosa woodsii* 3%
Total Shrub Cover: 10%
Grass Cover:
Forb Cover: 30%
Aspect: northwest
Slope: 28-30°
Insect/Disease:

Dominant Plant Species: *Mahonia repens*, *Carex geyeri*, *Paxistima myrsinites*

Notes:

MM_10

Photo file: MM_10n.jpg

Photo file: MM_10e.jpg

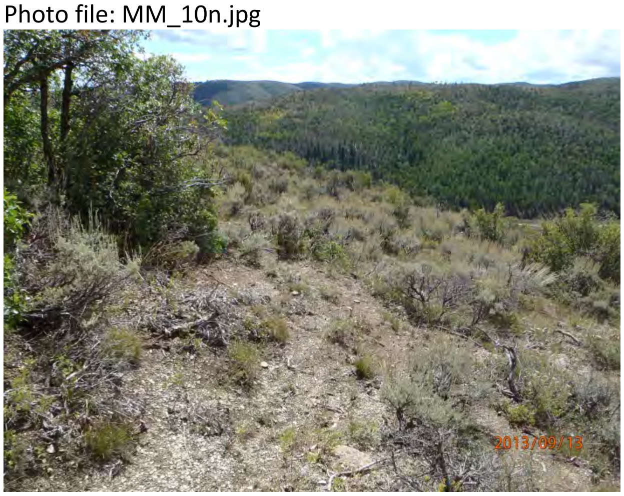

Photo file: MM_10s.jpg

Photo file: MM_10w.jpg

Plot ID: MM_10
Survey Date: September 13, 2013
Cover Type: Mixed mountain shrub
Sage Cover: 12%
Other Shrub Cover: *Amelanchier utahensis* 5%, *Purshia tridentata* 10%, *Symphoricarpos oreophilus* 3%, *Quercus gambelii* 3%, *Chrysothamnus viscossisimum* 1%
Total Shrub Cover: 30%
Grass Cover: 7%
Forb Cover: 3%
Aspect: West
Slope: 22°
Insect/Disease:

Dominant Plant Species: *Amelanchier utahensis*, *Purshia tridentata*, *Symphoricarpos oreophilus*, *Artemisia tridentata*, *Chrysothamnus viscosissimum*, *Eriogonum umbellatum*, *Lupinus spp.*, *Carex geyeri*, *Quercus gambelii*, *Oryzopsis hymenoides*, *Viscia americana*

Notes:

Pinyon-Juniper Points

PJ-02

Photo file: PJ_02n.jpg

Photo file: PJ_02e.jpg

Photo file: PJ_02s.jpg

Photo file: PJ_02w.jpg

Plot ID: PJ-02
Survey Date: August 30, 2013
Cover Type: *Quercus gambelii*
Sage Cover: 0%
Other Shrub Cover: *Quercus gambelii* 80%, *Prunus virginiana* 10%, *Amelanchier alnifolia* 4%, *Symphoricarpos oreophilus* 18%
Total Shrub Cover: 99%
Grass Cover: 19%
Forb Cover: 5%
Aspect: west
Slope: 45°
Insect/Disease:

Dominant Plant Species: *Quercus gambelii*, *Prunus virginiana*, *Amelanchier alnifolia*, *Symphoricarpos oreophilus*, *Carex geyeri*, *Paxistima myrsinites*, *Mahonia repens*

Notes:

PJ-04

Photo file: PJ_04n.jpg

Photo file: PJ_04e.jpg

Photo file: PJ_04s.jpg

Photo file: PJ_04w.jpg

Plot ID: PJ-04
Survey Date: October 9, 2013
Cover Type: *Quercus gambelii*
Sage Cover: 15%
Other Shrub Cover: oak 15%, amuta 5%, *Artemisia tridentata* 15%, *Chrysothamnus viscosissimum* 10%
Total Shrub Cover: 50%
Grass Cover: 85%
Forb Cover: 15%
Aspect:
Slope: 15°
Insect/Disease:

Dominant Plant Species:

Notes:

PJ-05

Photo file: PJ_05n.jpg

Photo file: PJ_05e.jpg

Photo file: PJ_05s.jpg

Photo file: PJ_05w.jpg

Plot ID: PJ-05
Survey Date: August 30, 2013
Cover Type: Mixed mountain shrublands
Sage Cover: 5%
Other Shrub Cover: *Quercus gambelii* 10%, *Amelanchier utahensis* 17%, *Symphoricarpos oreophilus* 5%
Total Shrub Cover: 60%
Grass Cover: 18%
Forb Cover: 10%
Aspect: west
Slope: 40°
Insect/Disease:

Dominant Plant Species: *Amelanchier utahensis*, *Quercus gambelii*, *Artemisia tridentata*, *Symphoricarpos oreophilus*, *Chrysothamnus viscossisimum*, *Carex geyeri*, *Pascopyrum smithii*, *Mahonia repens*, *Penstemon strictus*.

Notes:

PJ-06

Photo file: PJ_06n.jpg

Photo file: PJ_06e.jpg

Photo file: PJ_06s.jpg

Photo file: PJ_06w.jpg

Plot ID: PJ-06
Survey Date: August 30, 2013
Cover Type: Mixed mountain shrublands
Sage Cover: 15%
Other Shrub Cover: *Quercus gambelii* 45%, *Amelanchier utahensis* 17%, *Purshia tridentata* 10%
Total Shrub Cover: 80%
Grass Cover: 12%
Forb Cover: 4%
Aspect: east
Slope: 18°
Insect/Disease:

Dominant Plant Species: *Quercus gambelii*, *Amelanchier utahensis*, *Artemisia tridentata*, *Purshia tridentata*, *Carex geyeri*, *Lupinus spp.*, *Achillea millefolia*, *Eriogonum umbellatum*, *Collinsia parviflora*

Notes:

PJ-10

Photo file: PJ_10n.jpg

Photo file: PJ_10e.jpg

Photo file: PJ_10s.jpg

Photo file: PJ_10w.jpg

Plot ID: PJ-10
Survey Date: August 30, 2013
Cover Type: Mixed mountain shrublands
Sage Cover: 12%
Other Shrub Cover: *Amelanchier utahensis* 15%, *Cercocarpus montanus* 4%, *Symphoricarpos oreophilus* 4%
Total Shrub Cover: 36%
Grass Cover: 8%
Forb Cover: 17%
Aspect: west
Slope: 26°
Insect/Disease:

Dominant Plant Species: *Amelanchier utahensis*, *Artemisia tridentata*, *Cercocarpus montanus*, *Symphoricarpos oreophilus*, *Pascopyrum smithii*, *Eriogonum umbellatum*, *Oryzopsis hymenoides*, *Viscia americana*.

Notes:

Sagebrush Points

SA_02

Photo file: SA_02n.jpg

Photo file: SA_02e.jpg

Photo file: SA_02s.jpg

Photo file: SA_02w.jpg

Plot ID: SA_02
Survey Date: October 9, 2013
Cover Type: Sagebrush
Sage Cover: 65%
Other Shrub Cover: *Artemisia tridentata* 65%, *Symphoicarpos oreophilus* 3%, *Chrysothamnus viscosissimum* 2%, *Pinus edulis* 24%
Total Shrub Cover: 75%%
Grass Cover: 80%
Forb Cover: 8%
Aspect:
Slope: 9°
Insect/Disease:

Dominant Plant Species:

Notes:

SA_08

Photo file: SA_08n.jpg

Photo file: SA_08e.jpg

Photo file: SA_08s.jpg

Photo file: SA_08w.jpg

Plot ID: SA_08
Survey Date: October 9, 2013
Cover Type: Sagebrush
Sage Cover: 65%
Other Shrub Cover: *Artemisia tridentata* 65%, *Symphoicarpos oreophilus* 3%, *Chrysothamnus viscosissimum* 2%
Total Shrub Cover: 80%
Grass Cover: 80%
Forb Cover: 8%
Aspect:
Slope: 9°
Insect/Disease:

Dominant Plant Species:

Notes:

SA_09


Photo file: SA_09n.jpg


Photo file: SA_09e.jpg

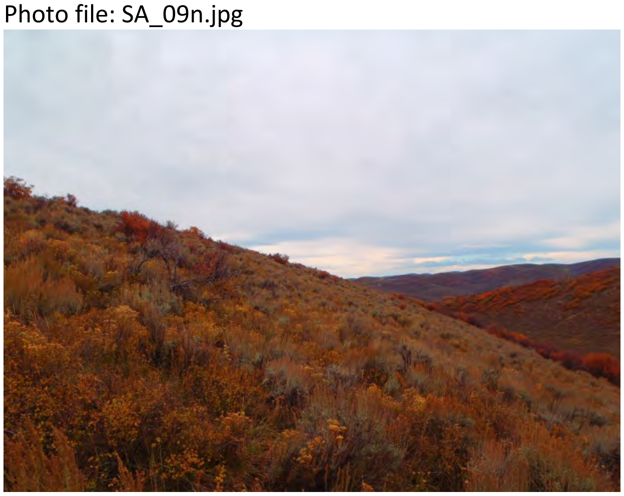
Photo file: SA_09s.jpg


Photo file: SA_09w.jpg

Plot ID: SA_09
Survey Date: October 9, 2013
Cover Type: Sagebrush
Sage Cover: 40%
Other Shrub Cover: *Artemisia tridentata* 40%, *Symphoicarpos oreophilus* 10%, *Chrysothamnus viscosissimum* 5%, *Amelanchier utahensis* 2%
Total Shrub Cover: 70%
Grass Cover: 75%
Forb Cover: 10%
Aspect:
Slope: 20°
Insect/Disease:

Dominant Plant Species:

Notes:

SA_10

Photo file: SA_10n.jpg

Photo file: SA_10e.jpg

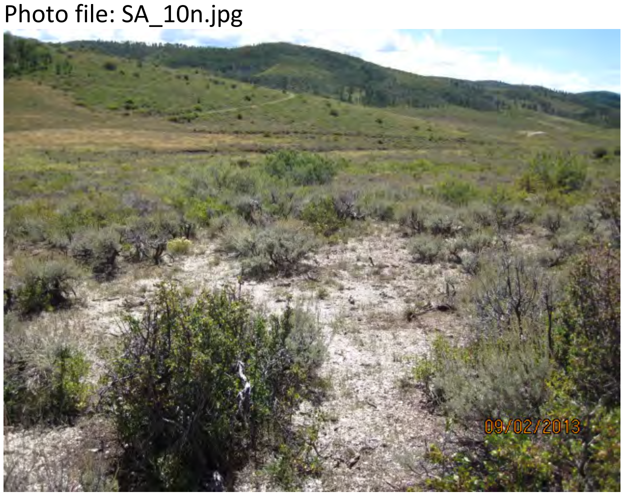

Photo file: SA_10s.jpg

Photo file: SA_10w.jpg

Plot ID: SA_10
Survey Date: September 2, 2013
Cover Type: Sagebrush
Sage Cover: 38%
Other Shrub Cover: *Artemisia tridentata* 38%, *Symphoricarpos oreophilus* 11%, *Amelanchier utahensis* 2%
Total Shrub Cover: 50%
Grass Cover: 8%
Forb Cover: 4%
Aspect: south
Slope: 8°
Insect/Disease:

Dominant Plant Species: *Artemisia tridentata*, *Symphoricarpos oreophilus*, *Amelanchier utahensis*, hetspp., *Lupinus spp*., *Castilleja* spp., *Chrysothamnus viscosissimum*, *Eriogonum* spp., *Pseudoroegneria spicata*, *Poa secunda*, *Comandara umbellata*.

Notes:

Extra-1


Photo file: Oops-1n.jpg


Photo file: Oops-1e.jpg


Photo file: Oops-1s.jpg


Photo file: Oops-1w.jpg

Plot ID: Oops-1
Survey Date: September 13, 2013
Cover Type: Sagebrush
Sage Cover: 35%
Other Shrub Cover: *Amelanchier utahensis* 1%, *Chrysothamnus viscossisimum* 25%, *Symphoicarpos oreophilus* 2%
Total Shrub Cover: 60%
Grass Cover: 30%
Forb Cover: 6%
Aspect: northwest
Slope: 5°
Insect/Disease:

Dominant Plant Species: *Eriogonum umbellatum*, *Comandara umbellata*, *Astragalus convallarius*, *Penstemon* spp., *Carex geyeri*, *Poa pratensis*, *Pseudoroegneria spicata*

Notes:

Sage-Grassland Points

SG_03

Photo file: SG_03n.jpg

Photo file: SG_03e.jpg

Photo file: SG_03s.jpg

Photo file: SG_03w.jpg

Plot ID: SG_03
Survey Date: September 25, 2013
Cover Type: Sage-Grassland
Sage Cover: 40%
Other Shrub Cover: *Artemisia tridentata* 29%, *Symphoicarpos oreophilus* 20%, *Chrysothamnus viscosissimum* 10%, *Amelanchier utahensis* 1%, *Quercus gambelii* 1 %
Total Shrub Cover: 58%
Grass Cover: 60%
Forb Cover: 8%
Aspect: East
Slope: 5°
Insect/Disease:

Dominant Plant Species: *Bromus inermis*, *Carex geyeri*, *Eriogonum umbellatum*, *Pseudoroegneria spicata*, *Chenopodium leptophyllum*

Notes: Grazed, nearby sage-grouse roost pile

SG_06

Photo file: SG_06n.jpg

Photo file: SG_06e.jpg

Photo file: SG_06s.jpg

Photo file: SG_06w.jpg

Plot ID: SG_06
Survey Date: September 13, 2013
Cover Type: Sage-Grassland
Sage Cover: 40%
Other Shrub Cover: *Artemisia tridentata* 40%, *Purshia tridentata* 15%, *Amelanchier utahensis* 1%, *Symphoicarpos oreophilus* 2%, *Chrysothamnus viscossisimum* 15%
Total Shrub Cover: 50%
Grass Cover: 40%
Forb Cover: 10%
Aspect: southwest
Slope: 5°
Insect/Disease:

Dominant Plant Species: *Carex geyeri*, *Poa pratensis*, *Pseudoroegneria spicata*, *Lupinus spp.*, *Helenium autumnale*, *Eriogonum umbellatum*.

Notes:

SG_07


Photo file: SG_07n.jpg


Photo file: SG_07e.jpg


Photo file: SG_07s.jpg


Photo file: SG_07w.jpg

Plot ID: SG_07
Survey Date: September 15, 2013
Cover Type: Sage-Grassland
Sage Cover: 23%
Other Shrub Cover: *Artemisia tridentata* 23%, *Purshia tridentata* 28%, *Amelanchier alnifolia* 6%, *Symphoicarpos oreophilus* 1%, *Chrysothamnus viscossisimum* 8%, *Quercus gambelii* 2%
Total Shrub Cover: 55%
Grass Cover: 10%
Forb Cover: 6%
Aspect: south
Slope: 13°
Insect/Disease:

Dominant Plant Species: *Pseudoroegneria spicata*, *Achillea millefolium*, *Eriogonum umbellatum*, *Penstemon* spp., *Opuntia polyacantha*, *Aster* spp.

Notes:

Sage- Mixed Mountain Shrub Points

SM_01

Photo file: SM_01n.jpg

Photo file: SM_01e.jpg

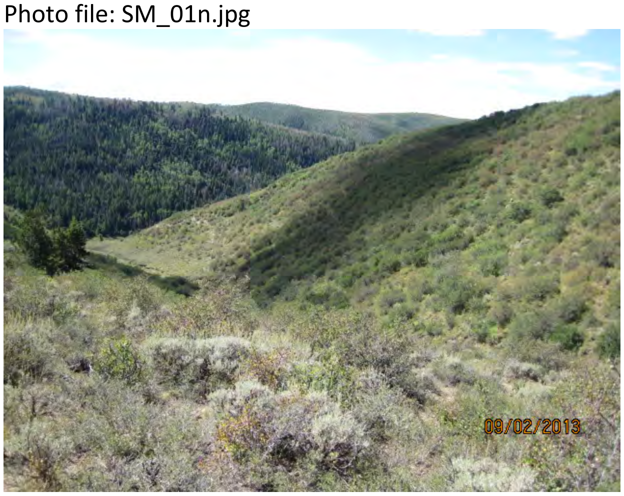

Photo file: SM_01s.jpg

Photo file: SM_01w.jpg

Plot ID: SM_01
Survey Date: September 2, 2013
Cover Type: Sage-mixed mountain shrub
Sage Cover: 7%
Other Shrub Cover: *Amelanchier utahensis* 40%, *Purshia tridentata* 30%, *Symphoricarpos oreophilus* 5%
Total Shrub Cover: 75%
Grass Cover: 6%
Forb Cover: 5%
Aspect: southwest
Slope: 20°
Insect/Disease:

Dominant Plant Species: *Amelanchier utahensis*, *Purshia tridentata*, *Symphoricarpos oreophilus*, *Artemisia tridentata*, *Castilleja* spp., *Chrysothamnus viscosissimum*, *Eriogonum umbellatum*, *Carex geyeri*, *Penstemon procerus*, *Poa secunda*

Notes:

SM_03


Photo file: SM_03n.jpg


Photo file: SM_03e.jpg

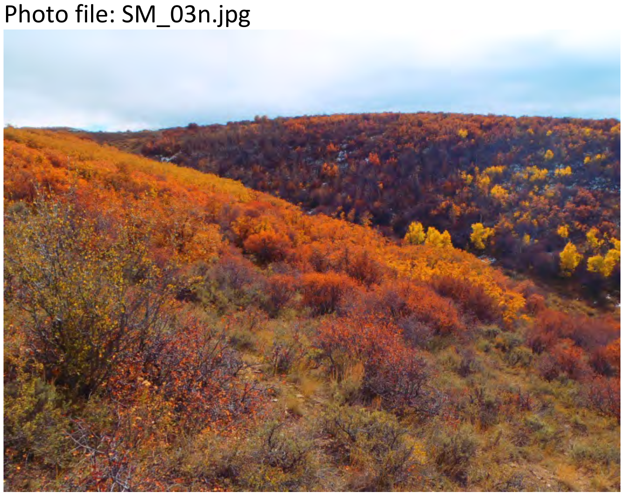
Photo file: SM_03s.jpg


Photo file: SM_03w.jpg

Plot ID: SM_03
Survey Date: October 9, 2013
Cover Type: Sage-mixed mountain shrub
Sage Cover: 10%
Other Shrub Cover: *Quercus gambelii* 10%, *Amelanchier utahensis* 20%, *Artemisia tridentata* 10%, *Symphoicarpos oreophilus* 2%
Total Shrub Cover: 55%
Grass Cover: 55%
Forb Cover: 5%
Aspect: southwest
Slope: 32°
Insect/Disease:

Dominant Plant Species:

Notes:

SM_04

Photo file: SM_04n.jpg

Photo file: SM_04e.jpg

Photo file: SM_04s.jpg

Photo file: SM_04w.jpg

Plot ID: SM_04
Survey Date: October 9, 2013
Cover Type: Sage-mixed mountain shrub
Sage Cover: 7%
Other Shrub Cover: *Quercus gambelii* 10%, *Artemisia tridentata* 12%, *Amelanchier utahensis* 5%, *Symphoicarpos oreophilus* 5%, *Chrysothamnus viscosissimum* 2%
Total Shrub Cover: 40%
Grass Cover: 80%
Forb Cover: 5%
Aspect:
Slope: 31°
Insect/Disease:

Dominant Plant Species:

Notes:

SM_09

Photo file: SM_09n.jpg

Photo file: SM_09e.jpg

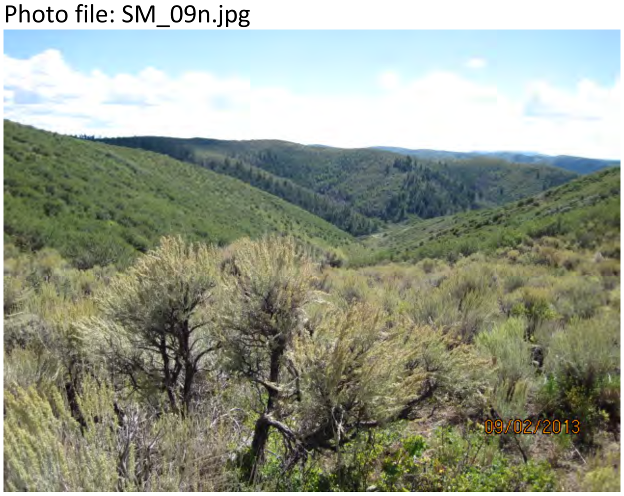

Photo file: SM_09s.jpg

Photo file: SM_09w.jpg

Plot ID: SM_09
Survey Date: September 9, 2013
Cover Type: Sage-mixed mountain shrub
Sage Cover: 60%
Other Shrub Cover: *Artemisia tridentata* 60%, *Symphorocarpos oreophilus* 20%, *Quercus gambelii* 2%
Total Shrub Cover: 80%
Grass Cover: 80%
Forb Cover: 10%
Aspect:
Slope: 4°
Insect/Disease:

Dominant Plant Species:

Notes: