SPATIAL DISTRIBUTION OF THE GREATER SAGE-GROUSE IN THE POWDER RIVER BASIN IN NORTHEASTERN WYOMING

by

Audra Smolek

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I dedicate this document to my parents for their constant support, close friends, and to my professors who have helped me through this educational endeavor: Drs. Wilson, Warshawsky, and Swift. Without the help and support of these individuals reaching this goal would have been much harder. I would also like to dedicate this accomplishment to my family who has always encouraged me to reach my goals.

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LIST OF ABBREVIATIONS

ASCII	Association of American Geographers
AUC	Area Under the Curve
BLM	U.S. Bureau of Land Management
CAS	Core Area Strategy
CSV	Comma Separated Value
ENM	Environmental Niche Model
FWS	Fish and Wildlife Service
GLM	Generalized Linear Model
GAM	Generalized Additive Model
Ha	Hectare
ROC	Receiving Operating Curve
SDM	Species Distribution Model
USFS	U.S. Forest Service
U.S.	United States
SDM	Species Distribution Model
SGIT	Sage Grouse Implementation Team
VGI	Volunteered Geographic Information

ABSTRACT

The greater sage-grouse is a very important species in the sagebrush landscape of the western U.S. The number of sage-grouse has declined due to habitat loss. This study charts the distribution of the greater sage-grouse in the Powder River Basin in northeastern Wyoming using the maximum entropy model MAXENT. The MAXENT model used variables important to the greater sage-grouse to create rasters that emphasized suitable habitat in Campbell and Converse counties. The first model used two biophysical factors (to mimic landscape suitability in the absence of people) and the second model used seven additional layers of distance to primary and secondary roads, gas processing facilities, power lines, pipelines, coal mines, and wells. The overarching goal was to document the impact humans have on the greater sage-grouse's habitat. Greater sage-grouse data has been collected since 1948 and these observations were used to develop the final models. The performance or accuracy of the model was based on the Receiving Operating Curve (ROC) and the Area Under the Curve (AUC) using 15 replicates of both models. Both of the models were able to predict the species distribution and achieved a rating of average in terms of performance. The two suitability maps produced by MAXENT highlight where the most acceptable habitats are located within the Powder River Basin. This is based on the environmental layers that were entered into MAXENT. The output can give researchers ideas of where best to place their conservation efforts for the greater sage-grouse. The greater sage-grouse is an important species because it is only found in North America and a small part of Canada. It is considered an umbrella species, meaning other species depend on its survival. The conservation of this species will benefit many other species that consider the 'sagebrush sea' their home.

CHAPTER 1: INTRODUCTION

The greater sage-grouse (*Centrocercus urophasianus*) is a flightless, migratory bird that is an essential species in the sagebrush landscape of the western U.S. The greater sage-grouse is important because it is considered an umbrella species, meaning that the sage-grouse has been selected for making conservation decisions. By protecting the greater sage-grouse we indirectly protect many other species that are part of the ecological community. The greater sage-grouse population has declined due to increased human development and the exploration of oil, natural gas, and coal across the region during the past 67 years. State and federal agencies are working on conservation plans that will help to decide whether or not to put the greater sage-grouse on the Endangered Species list. This decision will be made in September of 2015. Based on findings in 2010, the U.S. Fish and Wildlife Service (FWS) specifically recommended that the U.S. Bureau of Land Management (BLM) and the U.S. Forest Service (USFS) improve regulatory and management measures in their land-use plans in order to protect the greater sage-grouse habitat. Both agencies, the BLM and the USFS, have been updating management plans for the 70 million acres that they manage overall where the greater sage-grouse live. The BLM has documented the continuing loss, fragmentation and degradation of habitat associated with energy development (BLM, 2015).

The main objective of this study was is to determine suitable habitat areas for the greater sage-grouse within the Powder River Basin and identify possible environmental factors that affect the greater sage-grouse habitat. A habitat suitability map was created using a software program called MAXENT. The first map accounts for only biophysical layers and the second map includes both biophysical and human-environment layers or variables that impact the greater sage-grouse. The study identifies suitable habitat areas for the greater sage-grouse in

Campbell and Converse counties and provides maps of priority areas and how to protect and restore the greater sage-grouse species in the future.

Historically, the greater sage-grouse habitats were spread over 16 western U.S. states and three Canadian provinces. The grouse has disappeared from five of the 16 U.S. states (Nebraska, Kansas, Oklahoma, New Mexico, and Arizona) and two of the three Canadian provinces (British Columbia and Saskatchewan). The continued survival of the greater sage-grouse depends on the sagebrush steppe landscapes in 11 western states (Colorado, Wyoming, Idaho, Montana, Utah Washington, Oregon, Nevada, California, South Dakota, and North Dakota) and the Province of Alberta in Canada. Sagebrush steppe is basically a type of shrub that thrives in a dry-xeric environment that can be found in the western United States and parts of Canada.

The sagebrush ecosystems exist in the cold deserts of the western U.S. The sagebrush ecosystem extends from the Pacific Coast to the eastern portions of Colorado and Wyoming, and is centered on areas that range from semi-arid to arid (Figure 1). The sagebrush landscape covers 62 million ha (153 million acres). There are a variety of sagebrush species that occur in the region (USFS, 2015). The sagebrush is a major food source and provides essential habitat for the declining numbers of greater sage-grouse. Sagebrush ecosystems can be identified easily, because of their repetitive nature. By understanding the different types of sagebrush it helps determine soil depth, climate, topography, and wildlife species (Rosentreter, 2004). The reason the sagebrush is important to the west is because it serves as a ‘nurse’ plant for other plants, many of which are important to sustaining grazing wildlife (FWS, 2015).

Figure 1 Sagebrush landscape in northeast Wyoming
Photograph taken by Stephen C. Bunting

The sagebrush, when healthy, can live up to 150 years supporting various age classes and a diverse understory. This understory consists of grasses and forbs that can provide shelter and food for a variety of different species. Greater sage-grouse are not the only animal species that depends on the sagebrush. Many other species, including pygmy rabbits, sagebrush lizards, songbirds, mule deer, elk, and pronghorns, do as well. There may not be much diversity within the sagebrush ecological system, but the greater sage-grouse (Figure 2) live nowhere else in the world. Even though sagebrush has a long life span, factors can severely damage the plants' health. Disturbances caused by increased human encroachment and oil and gas drilling along with other factors can have negative impacts on plant health. It takes decades to centuries for the sagebrush to reestablish itself again (FWS, 2015).

Figure 2 Greater sage-grouse and chick
Photograph taken by ReaganGirl

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Since the greater sage-grouse can only be found in the sagebrush steppe of western North America, they utilize different types of sagebrush throughout the year for protection and food sources. The birds typically nest in sagebrush that has dense cover, big sagebrush for example (*Artemisaia tridentate*) (Cornell Lab of Ornithology, 2015). The sagebrush provides cover and food for the sage-grouse, especially during the winter months. The sagebrush is commonly found at low to mid elevations in valleys and mountain foothills (USDA NRCS Idaho State Office, 2011).

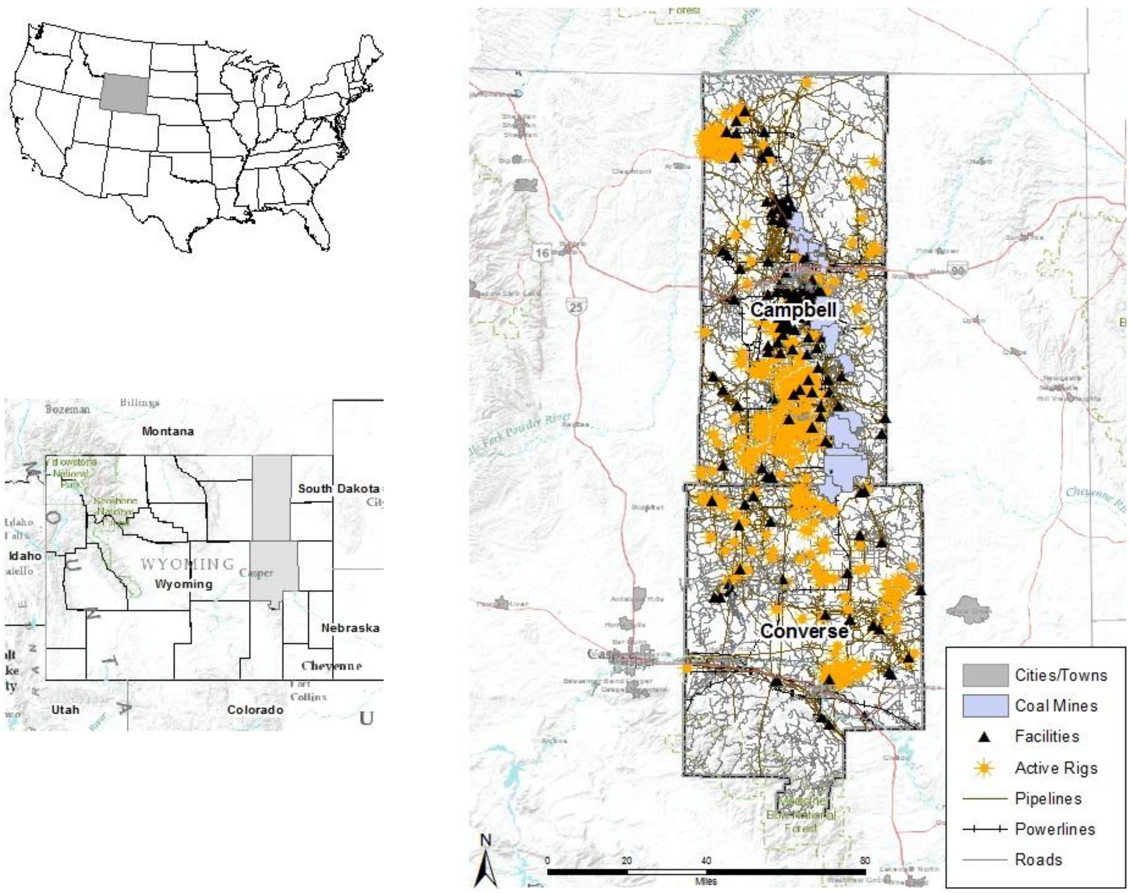

Figure 3 Map of Campbell and Converse counties in northeastern Wyoming showing active well locations, mines, gas plants, compressor sites, power lines, pipelines, roads and towns as well as the greater sage-grouse and sagebrush ecosystems

Sagebrush and the greater sage-grouse have maintained habitats in several western states; however, Wyoming and in particular the counties of Campbell and Converse are the focus of this study (Figure 3). These counties are located in the Powder River Basin in eastern Wyoming. The counties are home to sagebrush, the greater sage-grouse as well as mineral extraction.

Native Americans were the first inhabitants who used the sagebrush for hunting and other sustenance activities. During the colonization of the western U.S. the land was used for large-scale agriculture; however, more recently energy development has become more prevalent in the region (FWS, 2015). The Powder River Basin is a mineral rich region. The area ranks as one of the largest producers of coal in the U.S. and recently, with new technology to extract oil and natural gas from shale, the petroleum and natural gas industries have grown considerably as well. Many residents of the Powder River Basin work in the oil and gas and mining industries. There is also a strong ranching community. Over the years there have been booms and busts due to variations in oil and gas prices. This year, for example, there were a number of layoffs in the energy field. The Powder River Basin also experiences an influx of hunters during fall and winter each year. The growth of energy exploitation has created a fragmented sagebrush landscape in northeastern Wyoming. This causes significant impact on wildlife, because food, water and other resources are not distributed evenly across the landscape. Biodiversity has been lost due to fragmentation of the sagebrush landscape, and this has contributed to greater sage-grouse population declines.

The BLM and USFS are working with energy companies to do a better job of conserving the greater sage-grouse habitat by drilling only when the birds are not nesting/brooding and at a certain distance away from lek sites. Lek sites are traditional courtship display areas attended by male greater sage-grouse in or adjacent to sagebrush dominated habitat.

1.1 Thesis Organization

The remainder of this thesis is divided into four chapters. The next chapter describes the related work, providing some additional background information on the greater sage-grouse and the importance of sagebrush for its continued success, documenting the various explanations that have been asserted to have caused the decline in suitable habitat areas, and the methods and data sources that have been used to model species distributions and prioritize conservation and restoration goals for the greater sage-grouse and similar species across the western U.S. during the past 67 years.

The third chapter addresses the concept of maximum entropy and how it was used for the modeling and analysis performed. The presence only data for lek sites that have been collected in the field are described along with the model variables used to identify the distribution of suitable habitat. The procedures and protocols used to run the MAXENT model and evaluate the performance of the individual variables and the final models as a whole are outlined as well.

The fourth chapter presents the habitat suitability maps that resulted from the MAXENT model. A series of charts are also presented to show how each variable performed in the model, and a series of reports in MAXENT are presented in validate the various model outcomes.

The fifth and final chapter reviews the strengths and weaknesses of the MAXENT model and offers some suggestions for future work to support conservation of the greater sage-grouse in the Powder River Basin in northeastern

CHAPTER 2: RELATED WORK

This chapter describes the various species distribution modeling approaches that have been proposed and the ways in which they have been used. Special attention is paid to the design and application of the MAXENT model (Phillips and Dudik, 2008; Guisan and Zimmerman, 2000) that was utilized in this study.

2.1 Types of Species Distribution Models

Species distribution models (SDMs) are commonly used methods that take numerical tools and combine them with observations of species occurrence or abundance and environmental parameters to identify suitable or available habitats (Guisan and Zimmerman, 2000). Species distribution models can be used to provide an understanding of the ecology in specific landscapes and/or to predict the species' distribution across one or more landscapes. However, generally speaking, SDMs combine concepts from natural history with more recent developments in statistics and information technology. Generalized linear models (GLM) were originally used in early analyses of presence-absence and count data whereas generalized additive models (GAM), which are similar, can be used to describe nonlinear responses. However, in recent years MAXENT has become the new norm for simulating the spatial distributions of many different species.

Regression models simulate the response of variables to either a single or two or more environmental predictors. GLM models yield predictions within the limits of observed values and probability values between the extremes of presence and absence values (Guisan and Zimmerman, 2000). GAMs take into account the distribution of biological entities relative to environmental gradients, which are generated using non-parametric smoothing functions or predictors. The smoothing functions are usually applied independently to each predictor and then used additively to calculate the component response (Guisan and Zimmerman, 2000).

The maximum entropy model, MAXENT, is a newer example of a GLM (Elith and Lethwick, 2009). In maximum entropy estimation, the true distribution of a species is represented as a probability distribution π over the set X of sites in the study area. By using this approach, a model of π, a probability distribution that respects a set of constraints derived from the occurrence data, can be generated (Phillips and Dudik, 2008). MAXENT tries to fit environmental parameters or 'layers' based on the type and the complexity of dependencies in the environment. There are also a number of settings that can affect the performance and accuracy of this kind of model that are discussed in more detail in Chapter 3.

In ecology, GLMs have been recognized as having great advantages for dealing with data with different error structures particularly presence/absence data that is the most common type of data available for the spatial modeling of species distributions. GAMs are a powerful extension of GLMs and are increasingly used for species modeling (Austin, 2006). Species distributions are determined by environmental variables and the distribution of these variables can be estimated to help with this task.

In addition to GLMs and GAMs, environmental (or ecological) niche models (ENMs) use occurrence data in conjunction with environmental data to make a correlative model of environmental conditions and predict the suitability of the habitat (Warren and Seifert, 2011). ENMs are most often used in one or more of four ways: (1) to estimate the relative suitability of habitat that is known to be occupied by a specific species; (2) to estimate the relative suitability of habitat in a certain geographic region occupied by a species; (3) to estimate changes in the suitability of a particular habitat over some time period; and 4) to estimate the species' niche (Warren and Seifert, 2011). ENMs can use MAXENT to look at the effects of model complexity.

Even though there are similarities between MAXENT and GLM/GAMs there are some very important differences. GLM/GAMs are typically used to model the probability of occurrence. They also require absence data which means that when they are applied to presence-only data, background pixels must be used instead (Phillips et al., 2004). MAXENT supports a much clearer (i.e. cleaner) interpretation of the results, whereas GLM/GAMs are not as clear. It has been determined that MAXENT is much more closely linked to ENMs, due to their data requirements. This is due to the fact that GLM/GAMs are discriminative and may erroneously give better predictions when the training data is small (Phillips et at., 2004).

2.2 MAXENT Model and Applications

Maximum entropy or MAXENT is a highly sophisticated, machine-learning method of modeling a species' geographic distribution. Using data points of observed species (presence-only), and environmental conditions, MAXENT can estimate the environmental requirements of a species. MAXENT produces habitat suitability analyses addressing the spatial extent of a species. MAXENT has become the most commonly used software for inferring species distributions, species niches, and environmental tolerances, and it allows users to fit models of varying complexity (Warren and Seifert, 2011).

MAXENT has been used in numerous research studies in recent years. It has proven to be a very helpful tool in predicting suitable habitats for specific species. The performance of the model can be tested through the occurrence data generated through observations. The following paragraphs describe several examples of how the MAXENT model has been used in different regions to predict habitat suitability for different species.

In Iowa, researchers wanted to be better equipped to plan for mosquito control to help prevent the spread of the West Nile Virus. Researchers used MAXENT to predict potential West Nile Virus vector species distribution (Larson et. al, 2010). Occurrence data of two different mosquito species (*Culex tarsalis L* and *Culex pipiens Coquillett*) were used in the model, because they are the most likely to be the transmitters of the West Nile Virus. The environmental variables that were used in the model were annual temperature, precipitation, slope, aspect, compound topographic index, distance to major and minor rivers, land cover, distance to urban areas, and available soil water content. The MAXENT model was set up using 80% of the occurrence records, the final 20% of the occurrence records which were set aside for external validation, and the maximum number of iterations was set to 1,000. MAXENT provided multiple raster images of the two different mosquito species along with ROC and AUC curves. Based on knowledge known about the area it was deemed that the Cx. Tarsalis habitat was located in areas where irrigation is used for crops, which was expected. Cx. Pipiens are known as an urban species and the model predicted their locations in or near residential and commercial areas. The models performed quite well, the AUC values were 0.936 and 0.935 for the two different species. If the model had a rating of 1 it would have been a perfect analysis. It was determined that the probability distribution maps were a good starting point for understanding the transmission of mosquito-borne pathogens in Iowa. MAXENT was also able to fit the occurrences of mosquito species without over predicting the area in which they are able to live.

The Hawai'i County Crop Model project set out to create an interactive, web-based agricultural land planning tool that would assist planners and assess environmental conditions at certain locations which would advise on what kinds of crops might be grown there (Kemp, 2012). The model used eight different crop types: flowers and foliage, tropical fruits, papaya, banana, coffee, macadamia nuts, specialty crops, and truck crops. The study also incorporated soil and non-soil environmental layers. The non-soil layers were elevation, slope, temperature (minimum annual, and maximum annual), rainfall (minimum monthly, maximum monthly, and total annual) and solar radiation. The soil layers included pH, bulk density, available water capacity, organic matter, surface texture, depth to any soil restrictive layer, drainage class, flood class, map unit, representative slope, effective cation-exchange capacity, and crop productivity index. The MAXENT model was set up with logistic as the output type. It is the easiest to conceptualize. The number of replicates was set at 100 and the default prevalence was adjusted to 0.8 rather than the default of 0.5. The default of 1 was used for the regularization multiplier, which defines how closely the probability distribution is fitted to the observation data. The Random Seed was set to yes, because it would give the best possible range of results. The maximum iterations and the convergence threshold were placed at 500 and .00001 respectively, which are the defaults. Interestingly enough the soil data provided very little contribution. The outputs from the model included some useful tables, one in particular showed the percent contribution and permutation importance of each variable. The results of the MAXENT model in this study were deemed not definitive, because slightly different results could be generated with each model run (Kemp, 2012). The final models were sufficiently stable and the final Crop Probability Maps may become important contributions to land use planning in Hawai'i in the future.

A study off the Southern California coast used MAXENT to identify and analyze suitable habitats for the blue whale. Bissell (2013) created a dataset describing whale presence locations using volunteered geographic information (VGI), comprised of observations taken from whale watching vessels. This study included environmental variables such as bathymetry, sea surface temperature, and chlorphyll-a. The presence locations were collected using science-quality whale observations and by whale watching observations from commercial vessels. The MAXENT model was set up using the recorded whale observations stored in CSV format and the environmental variables were converted to ASCII format so they could be utilized in the MAXENT model. The number of samples used for testing was set to 25 percent, these were randomly selected, and the model used 15 replications. The model created percent contribution tables and rasters that showed high and low habitat suitability for the blue whale. The model also produced ROC and AUC graphs that rated the models' performance. The observations made by commercial whale watching vessels proved to be instrumental in this particular study. By using these data, the MAXENT model had sufficient information to predict suitable habitat areas for the whales. The models performed quite well with very high AUC ratings of 0.945 and 0.953. The outcomes from this study proved that observational data can be very beneficial for future marine spatial planning. The results also showed how this information can be used to mitigate marine traffic impacts by informing the maritime community of the locations where may take place.

The MAXENT model can also be used in ENMs. Warren and Seifert (2011), for example, looked at the effects of model complexity on ENMs using MAXENT for 51 different species in California. The analysis used occurrence data for these 51 species obtained from the Museum of Vertebrate Zoology at the University of California, Berkeley. The environmental layers that were used included slope, altitude, GAP vegetation type, and 19 other layers that were referred to as "Bioclim" layers, which represent various aspects of temperature, precipitation, and seasonality (Warren and Seifert, 2011). Each of the 51 species had 10 different levels of complexity (1, 3, 5, 7…19). The weighted occurrence points were sampled 100 times and then repeated using 1,000 simulated occurrence points, which determined the effects of sample size on model performance. Twenty percent of the occurrence data records were withheld from each model run to be used as independent test data. The remaining settings in MAXENT were left as the defaults. Based on the data applied to the MAXENT model, a series of rasters were created that identified the extent of over- or under-parameterization for 100 and 1,000 occurrence points. The model also looked at future suitability. The model showed that all criteria except AUC training performed better when given more data; however, when AUC training is used as a model criteria, it performed worse on the data sets containing 1,000 occurrence points than on data sets containing 100 points (Warren and Seifert, 2011). This could be explained by the tendency of MAXENT to favor over-parameterized models. The model was considered statistically significant from all the different rankings in the model. The interesting idea that this study concluded was that the model complexity affects the users' ability to infer the suitability of habitat both with and without thresholds, the relative importance of environmental variables to determine species distributions, estimates the reach of species' environmental niches, and the transferability of models (Warren and Seifert, 2011).

These examples, taken as a whole, help to paint a picture of how the MAXENT model has been used in different regions and for different species. The next chapter examines the variables used in this particular study more closely as well as the performance of each of the variables in the greater sage-grouse model generated for this thesis research project.

CHAPTER 3: METHODS AND DATA

The field data and methodology are described in this chapter. The concept of maximum entropy, the presence only data, the model variables, the MAXENT model, and the procedures used to assess model and variable performance are discussed in successive sections below.

3.1 Typical Species Distribution Model Workflow

To start this process and form an ecological model it is critical to understand the framework of the elements that are incorporated in the MAXENT model. The free MAXENT model (Version 3.3) was downloaded from the MAXENT website (https://www.cs.princeton.edu/~schapire/maxent/; IPCC Data Distribution Center, 2011). The major challenge for determining the suitable habitat for the greater sage-grouse were understanding which environmental layers were the most important to the species.

The flow chart (Figure 4) below depicts the process that was followed from start to finish in this study. It provides a high level overview of what was accomplished by using MAXENT. The flow chart breaks down the tasks that were completed in each phase of the study. It speaks to the types of file types that were created in order for MAXENT to run successfully as well as the results of the two sets of model runs. Both sets of model results describe the areal extent and suitability of the greater sage-grouse habitats across the Powder River Basin.

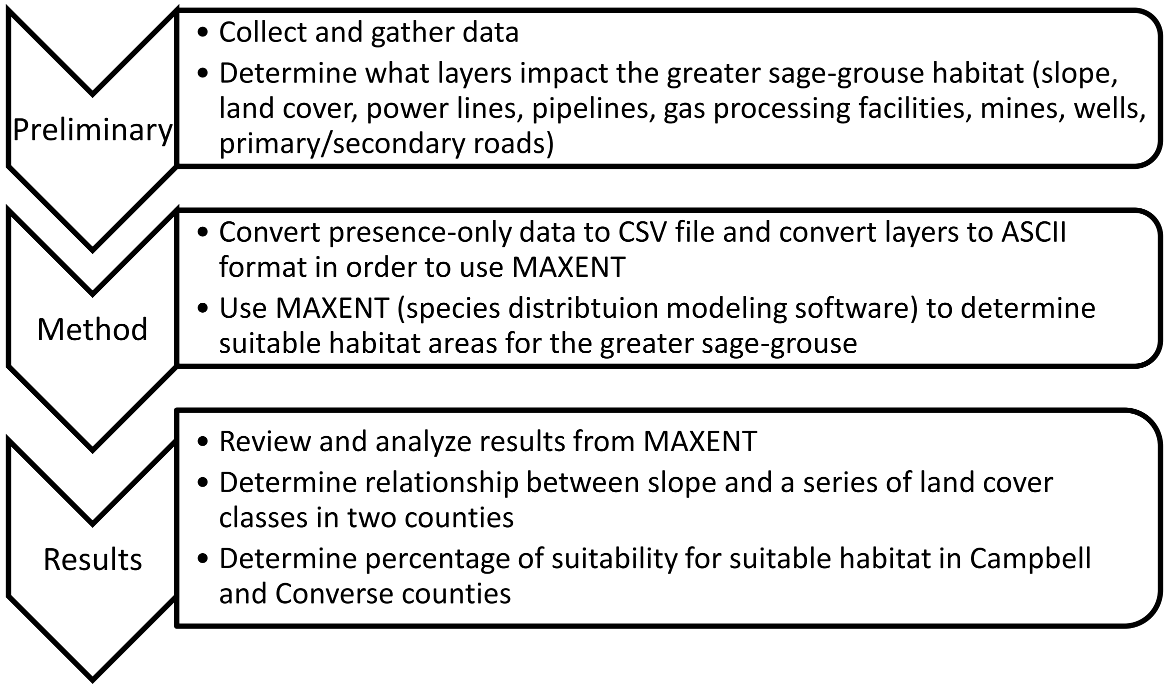

Figure 4 Flow chart of methodology for study of the greater sage-grouse using MAXENT

The biophysical and other environmental layers or variables that were incorporated in this study were slope, land cover, pipelines, primary and secondary roads, wells (rigs), power lines, coal mines, and facilities (i.e. gas plants and compressor stations). Slope and land cover (biophysical) are two very important elements for the greater sage-grouse. The species prefer slopes that are ≤ 5% and they depend on sagebrush (land cover) for their survival throughout the year. The final seven environmental layers were selected to represent the anthropogenic impact on the greater sage-grouses' habitat areas in the Powder River Basin.

The intent of the model was to understand how slope and land cover predict suitable habitat, by creating a model using only those two layers along with the lek sites. The second model looked at how slope and land cover, along with the final seven environmental layers affected the greater sage-grouse's habitat suitability. The MAXENT model can only be run with CSV and ASCII file types. The presence-only lek site greater sage-grouse observation data that were also utilized in this model were converted into the CSV format and the two biophysical and seven environmental variables were saved as ASCII files. The acquisition and characteristics of the various model inputs are described next.

3.2 Presence Data

Since MAXENT uses presence-only data, greater sage-grouse observations were obtained from the Wyoming State Fish and Wildlife Department. The point data had been collected from 1948 to the present and included occupied lek sites. Lek sites are large, open areas where greater sage-grouse preform ritual mating dances in the early spring, March through early May. These data points were converted into a CSV (comma separated value), because MAXENT can only work with this file format for presence-only data. The data records specify the locations of lek sites. In all 256 lek sites were identified as occupied and used in the study. The majority of the lek site data was collected from the late 1970s to 2014. The locations of these lek sites spanned private land as well as federally owned lands.

3.3 Explanatory Variables

The layers chosen as potential or candidate variables were determined based on research conducted from various studies that have been conducted on the greater sage-grouse and also by speaking with specialists in Wyoming who work on the conservation of the greater sage-grouse. Table 1 lists the variables that were used for this study, offers a short description of each variable, and lists the sources used to acquire the data for each of these variables.

Table 1: List of explanatory variables and data sources

Variables	Explanation	Source
Slope	Greater sage-grouse prefer slopes of ≤5%	USGS NED (National Elevation Dataset) (n43w106 1 arc-second 2013 1 x 1 degree ArcGrid (USGS, 2015)
Land cover	Sagebrush is a necessary plant species for the survival of the grouse	Gap Analysis Projects/LANDFIRE Project, NatureServe's Ecological System Classification
Distance to roads/primary and secondary	Road allow access to and from areas, but facilitate sage-grouse collisions with vehicles	Pennwell base data within the PODS database (Pipeline Open Data Standard)
Distance to power lines	Provides electricity to facilities, provide roosting sites for predatory birds	Pennwell base data within the PODS database
Distance to pipelines	Pipelines transport oil & natural gas, but disturb the landscape and remove sagebrush	Pennwell base data within the PODS database
Distance to mines	Coal mines extract minerals from the Earth, but disturb the surface and accompanying land cover	WhiteStar base data within the PODS database
Distance to gas processing facilities	Facilities compress and process gas, disturbing the surface and accompanying land cover and creating noise	Pennwell base data within the PODS database
Distance to wells	Well locations provide extraction of oil and natural gas	PODS database-IHS Active Rigs (USGS, 2015)

Slope is important for the greater sage-grouse because the species prefers slopes of 5% or less. Slope, however, is considered an indirect gradient, which means that it has no direct physiological relevance for the species' performance (Guisan and Zimmerman, 2000). A digital elevation model (DEM) with square grid cells measuring 30 m on a side was downloaded from the USGS website and used to compute slope in percent (USGS, 2015). The National Elevation Dataset (NED) provides basic elevation information for earth science studies and mapping applications (USGS, 2015). The NED layers are seamless and are distributed in geographic coordinates at different scales. The DEMs used for this study were created by NED in February of 1999. Several DEMs mosaic tiles had to be downloaded in order to cover the two counties. The different tiles were then merged together using the mosaic to new raster tool.

Land cover is a very important biophysical variable for the greater sage-grouse. The greater sage-grouse depends on this vegetation for their survival throughout the year. The land cover dataset combines the work of several projects and provided a seamless dataset for the study area. Data from four regional GAP Analysis Projects and LANDFIRE projects were combined in order to make this dataset. Multi-season satellite imagery (Landsat ETM+) from 1999-2001 and a DEM (30 m) were used to create the final dataset with vegetation classes taken from NatureServe's Ecological System Classification. The dataset contained 105 different vegetation classes.

The remaining environmental layers were all gathered from a PODS database provided by Pennwell and WhiteStar, which are companies that create very large, national datasets for companies to purchase and use in analysis. All the data from these third party providers are updated quarterly with new features. Primary and secondary roads, power lines, pipelines, mines, facilities, and wells were incorporated into the analysis from Pennwell and WhiteStar. These seven layers have been introduced to the landscape of the Powder River Basin and the goal was to determine how have impacted the greater sage-grouse habitat. The installation dates for the environmental layers all vary. Large numbers of pipelines were built during boom times in the oil and gas industry when rigs were plentiful in the Powder River Basin. Many miles of pipelines and roads were installed in the 1970s and 1980s. Some of the pipeline documentation is missing; therefore, the date of installation is not clearly defined.   Over the last year, construction of these environmental layers have been reduced greatly due to decreased demand. Roads are created during these times in order to access the pipelines and wells in the sagebrush landscape. As more infrastructure was created in the region, more power lines were constructed as well.

Before MAXENT could be utilized, the layers needed to be adjusted to fit certain criteria. Since it has been determined that the greater sage-grouse prefer slopes of ≤ 5%, steeper slopes were removed from the dataset. A Mask was then applied to the slope layer to fit the study area consisting of the two counties (Figure 1). The next step was to use the Reclass tool to create a binary layer, where 1 is slopes ≤ 5% and 0 was everything else. In order for the layer to be used in MAXENT it then had to be converted into ASCII format. The same process was used for land cover although the land cover classes had to be adjusted to fit the needs of the greater sage-grouse. Since the original land cover dataset had 105 different vegetation classes, not all of them are suited for the greater sage-grouse. Only three of the 105 classes were selected: Columbia Plateau Low Sagebrush Steppe, Inter-Mountain Basins Big Sagebrush Steppe, Inter-Mountain Basins Montane Sagebrush Steppe. Similar to the slope layer, the land cover layer was then reclassed as binary (1 for the three previously mentioned vegetation classes, 0 for everything else) and converted to the ASCII format.

The process for the other seven layers incorporated an extra step. The layers gathered from Pennwell and WhiteStar were shapefiles that were clipped to fit the extent of Campbell and Converse counties similar to the slope and land cover layers. However, Euclidean distance analysis was applied to the seven layers. The Euclidean distance tool takes vector files, such as points, polygons, and poly lines and then creates a raster buffer around each of the layers. In this particular case a raster buffer of 1.6 miles was utilized to match previous research conducted by state GIS analysts. They have deemed that anything within that distance is unsuitable for the greater sage-grouse. The 1.6 mile raster buffer was placed around the environmental layers.

Both the slope/land cover and the seven environmental layers were projected to the WGS 1984 coordinate system. The extents of the rasters were set to -106.0016, 45.0016 and -104.9983, 41.9983 degrees of longitude and latitude, respectively to match the existing county extents. The new raster layers were then converted into ASCII layers for input into MAXENT. Once the layers matched the correct format for MAXENT, the data were added to the program. The CSV file is added to the Samples and the ASCII layers are added to the Environmental layers inside MAXENT. Table 2 describes the values used for the additional MAXENT settings.

After the model has been run successfully, a set of charts and graphs are created, based on the selections made from the settings chosen in the model. The first graph in the output folder is the analysis of omission/commission, which displays the omission rate and predicted area at different thresholds. The next graph is the sensitivity vs. 1-specificity; this is a graph of the Area Under the Receiver Operating Characteristic (ROC) Curve of the Area Under the Curve (AUC). The AUC allows the comparison of the performance of one model to another. This value indicates how the model performed; the closer to 1.0 the better the model performed. Analysis of layer contributions is supported by another table included in the output. This table shows the environmental variables that were used in the model and the percent predictive contribution of each variable. The higher the contribution, the more impact that particular variable had in predicting the occurrence of that species. Finally, the jackknife of regularized training gain shows the training gain of each variable if the model was run in isolation, and compares it to the training gain with all of the variables (Young et al., 2011). These aspects are described in more detail below.

3.4 MAXENT Model Runs

Two models were run using the Maxent modeling software. The first model included slope and land cover or the biophysical layers and the second model included slope, land cover and the seven other environmental layers: mines, primary and secondary roads, wells, facilities, power lines and pipelines. The settings that were applied were taken from a tutorial created by Nick Young, Lane Carter and Paul Evangelista for Colorado State University's Natural Resource Ecology Laboratory and the National Institute of Invasive Species Science (Young et al., 2011) (Table 2). The first model highlights habitat suitability if there were no further external human factors affecting the greater sage-grouse. The second model takes into account the environmental impacts that can be attributed to present-day human activity.

Table 2 MAXENT Model Parameters and Constraints

Number of overall samples	256
Regularization multiplier	1
Maximum number of background points	10,000
Number of replicates	15
Maximum number of iterations	5,000
Output format	Logistic
Convergence threshold	0.0001

To better understand Table 2 the number of samples refers to the presence-only data (lek sites) and the regularization multiplier can be thought of as a smoothing parameter, where larger values increase the amount of smoothing. The fewer background points that are assigned give a larger probability to each cell. The replicate option can be used to conduct multiple model runs for the same species. The number of iterations allows the model to have adequate time for convergence, if it does not have enough time to converge; it may over- or under-predict the relationships. Logistic output is the easiest to conceptualize; it gives an estimate between 0 and 1 representing the probability of presence (Phillips and Dudik 2008).

3.5 Assessment of Model and Variable Performance

The sensitivity vs. 1-specificity graph that was created shows the Area Under the Receiver Operating Characteristic (ROC) Curve of the Area Under the Curve (AUC). The AUC value allows the comparison of the performance of one model to another. An AUC rating of 0.9-1.0 results in a perfect test and an AUC rating of 0.5-0.6 represents a failing to poor test (Table 3). The training AUC was produced by comparing the calculated value with the maximum value for the area under the receiver operating characteristic curve, which was also calculated using the data in the model. The AUC test data was used to select the model that produced the maximum AUC value on randomly selected test data that was withheld form the model (Warren and Seifert, 2011).

Table 3 MAXENT Model Performance and Ratings (Source: Jablonicky, 2013)

AUC Value	Model Performance
0.9-1	Excellent
0.8-0.9	Good
0.7-0.8	Fair
0.6-0.7	Poor
0.5-0.6	Fail

The MAXENT model produced a series of charts known as jackknife charts in addition to the ROC graphs. The jackknife charts highlighted which layers were the most important to the model based on the training data. The jackknife withholds one predictor and refits the model for test data, and for training data it withholds all predictors but one and refits the model. By comparing these jackknife plots, the single variable that was the most effective for predicting the distribution of the occurrence data can be determined (Phillips and Dudik 2008). Finally, the jackknife of regularized training gain shows the training gain of each variable if the model was run in isolation, and compares it to the training gain with all of the variables (Young et al., 2011). To understand training and test data, the data is spilt into training and test sets. The model was trained/tuned with the training set and the tests determined how well it generalized to data it had never seen before. The model's performance on the test data set provided insights on how the model had performed. There is no rule on how big or small the training and test data sets should be.

MAXENT was used to create two raster maps for Campbell and Converse counties. The first raster or model, shows the suitability for greater sage-grouse based on slope and land cover. The second raster shows the suitability estimated with slope, land cover and several other environmental layers. These rasters highlight suitable sage-grouse habitat in Campbell and Converse counties using an arbitrary scale ranging from 0.0 (not suitable) to 1.0 (highly suitable). When the lek sites are overlaid they tend to fall within these suitable areas in the counties.

CHAPTER 4: RESULTS

The results of the MAXENT model runs are presented in this chapter along with the greater sage-grouse observation data and how slope and land cover along with the environmental layers affect the suitability of the greater sage-grouse habitat. The maps and charts in this chapter display the contributions of the explanatory layers and highlights the ROC and AUC of the data and regularized data. Habatit suitability maps based on presence-only data, biophysical and environmental layers represent the final results.

4.1 Greater Sage-Grouse (*Centrocercus urophasianus*) Observation Data

Greater sage-grouse have been observed 256 times at lek sites scattered throughout the two counties since 1948 (Figure 4). Campbell County has 195 lek sites or 76% compared to Converse County which only has 61 lek sites or 23%.

4.2 Contributions and Importance of Variables

Slope contributed the most to the biophysical model at 96.01%. Land cover did not appear to be as important to the model, because it contributed only 3.9% in the biophysical model (Table 4).

The contributions of both the environmental and biophysical layers that were included in the model are summarized in Table 5. Slope was the most important biophysical layer contributing to 29.2% to this model. Distance to mines provided the second largest contribution to the combined model at 28.5%, followed by distance to facilities at 13.4% and distance to primary roads at 9.8%. The other variables contributed 8.3% (secondary roads), 3.8% wells, 3.6% power lines, 3.1% land cover, and 0.3% pipelines 0.3% (Table 5).

Tables 4 and 5 give the relative contributions of the biophysical and environmental layers to the MAXENT model based on the percent contribution for each variable.

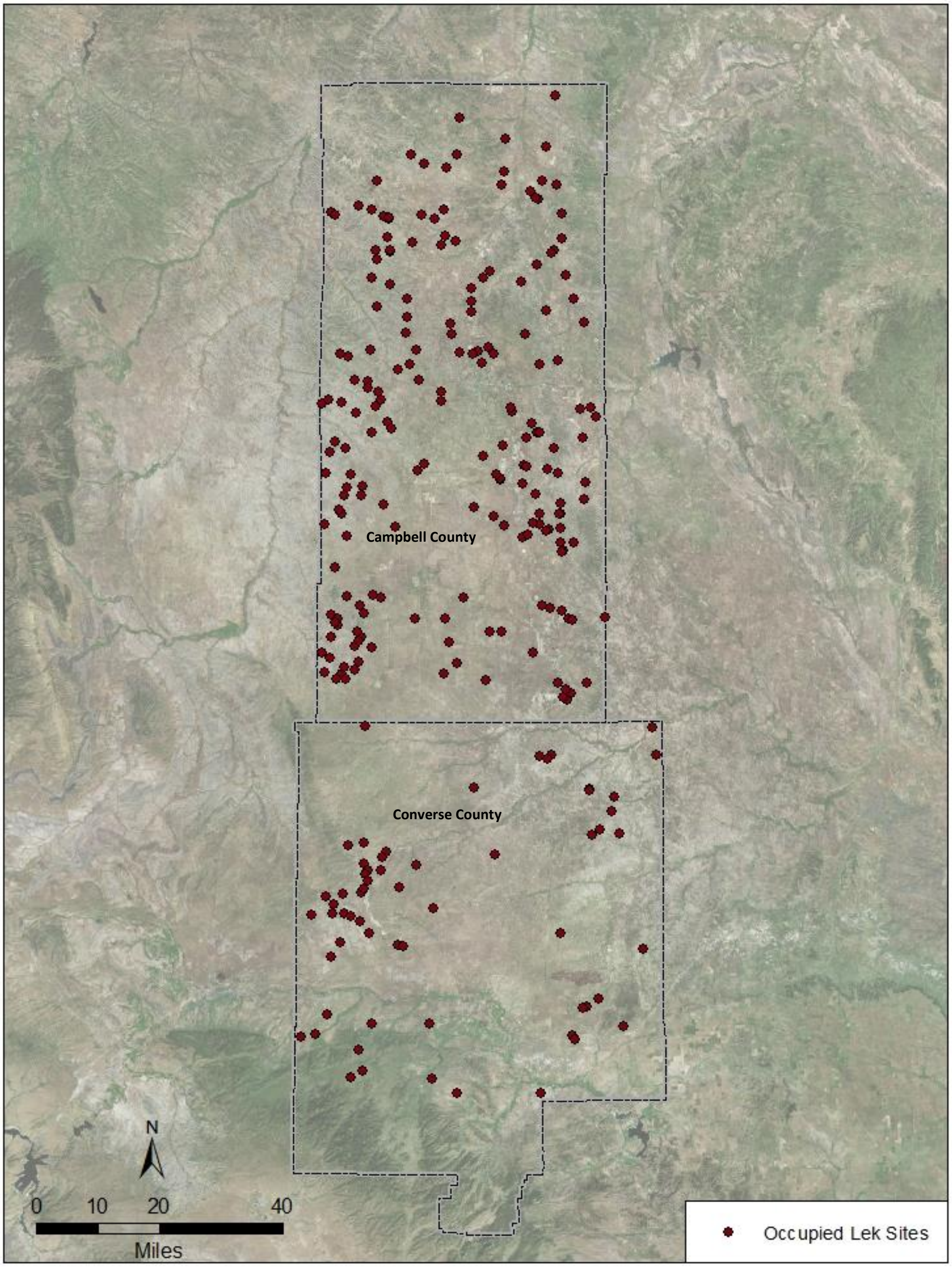

Figure 5 Map of lek sites of the greater sage-grouse in Campbell and Converse Counties

Table 4: Percent contributions of the two biophysical layers to the MAXENT model

Variables	Percent Contribution
Slope	96.01
Land Cover	3.9

Table 5: Percent contributions of the biophysical and environmental layers to the MAXENT model

Layers/Variables	Percent Contribution
Slope	29.2
Land Cover	3.1
Distance to Facilities	13.4
Distance to Pipelines	0.3
Distance to Power lines	3.6
Distance to Wells	3.8
Distance to Roads (primary)	9.8
Distance to Roads (secondary)	8.3
Distance to Mines	28.5

There were three primary land cover types that the greater sage-grouse prefer in Campbell and Converse counties: the Inter-Mountain Basins Big Sagebrush Steppe, the Inter-Mountain Basins Montane Sagebrush Steppe**,** and the Wyoming Basins dwarf Sagebrush and Steppe. Table 6 shows the percentage of each type of land cover in the two counties along with the amount of square kilometers for each particular land cover and the amount of slope less than or equal to five percent in the two counties. Converse County includes all three land cover types; however Campbell only has Inter-Mountain Basins Big Sagebrush Steppe. Table 6 also shows the average or mean slope of the land where specific land cover types are located in the two counties. The table also interprets the amount of suitable slope for the land cover types. Suitable slope in this instance is less than or equal to five percent, due to greater sage-grouse preference. Table 6 illustrates that Inter-Mountain Basins Big Sagebrush Steppe has the highest percentage of slope with less than five percent slope and covers the most land in the two counties. Based on data collected from land cover datasets Campbell County contains Inter-Mountain Basins Big Sagebrush Steppe, other vegetation is not as suitable for the greater sage-grouse.

Table 6: Geographic extent of suitable habitat and distribution of slopes in Campbell and Converse Counties, Wyoming

Land cover Type	Campbell County			Converse County		
	Area (km^2)	Mean Slope	% with Slope ≤5%	Area (km^2)	Mean Slope	% with Slope ≤5%
Inter-Mountain Basin Big Sagebrush Steppe	1286.9	7.2%	52%	1236.4	7.46%	49%
Inter-Mountain Basin Montane Sagebrush Steppe	N/A	N/A	N/A	238.7	12.2%	31%
Wyoming Basin Dwarf Sagebrush & Steppe	N/A	N/A	N/A	44.4	8.1%	28%
Other	2685.3	3.1%	52%	3074.8	3.2%	46%

4.3 Model Validation

The ROC plots the sensitivity against the 1-specificity as well as the corresponding AUCs documenting model performance. Figure 6 highlights the omission rate and predicted area as a function of the cumulative threshold for the biophysical layers, slope and land cover. The omission rate is calculated both on the training presence records and the test records, and this model had a score of 0.651 (Figure 5). Figure 7 incorporates the environmental layers as well as the biophysical layers and had a rating of 0.714. The red line shows the mean AUC value, while the blue line represents the omission on training samples. The black line represents the standard deviation value, which is also a random prediction that is set at 0.5. This means that if a model were to rate a 0.5 it is a random model (Phillips and Dudik 2008).

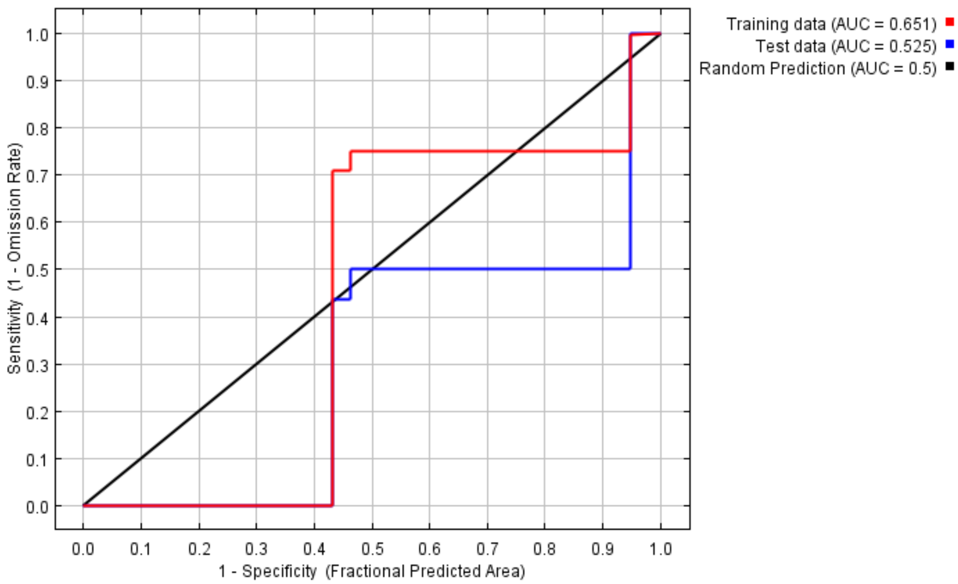

Figure 6 Average Sensitivity vs. 1 – ROC plots, biophysical layers in this instance. Slope and land cover are important features for the greater sage-grouse. The AUC rating for this model is 0.651

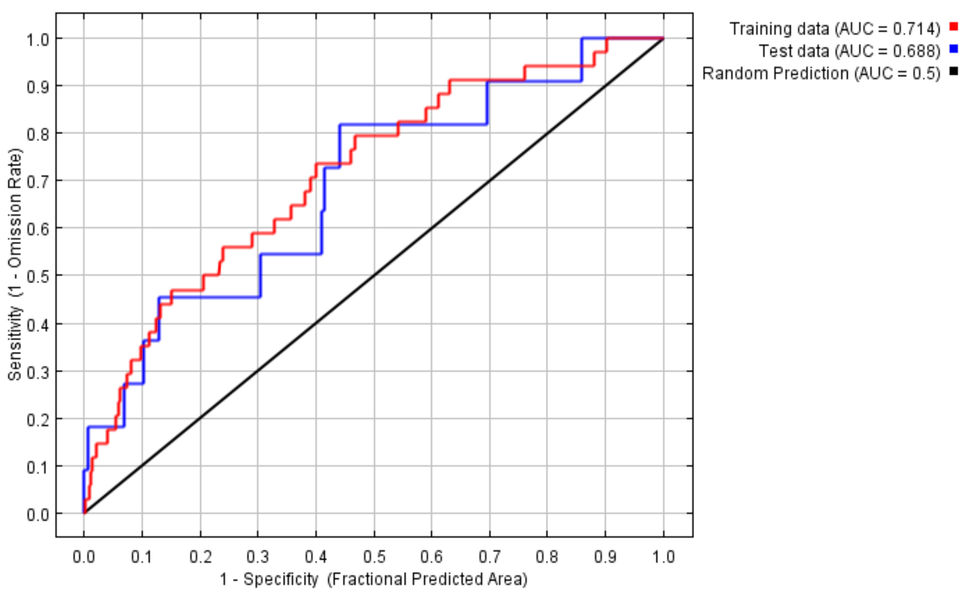

Figure 7 Average Sensitivity vs. 1 – ROC plots, environmental variables. The AUC rating is 0.714 for this model

The graphs reproduced in Figures 8-11 show the test and training gain of each layer when the model was run in isolation and compares it to the training gain with all of the layers. The jackknife graphs are important because they identify which variables contributed the most individually (Young et al., 2011). The test data for both models confirmed that slope was the most important layer to the model; however in the jackknife tests distance to mines is relevant when run in isolation. Regularized training gain is a method that relaxes the constraints of the model, because it is not necessary to fit the constraints exactly. Regularization in the model basically adds some junk, or background points, to the gain function so that it does not fit the observed presences too tightly, this can be seen in Figures 8 and 9 (University of Connecticut, 2011).

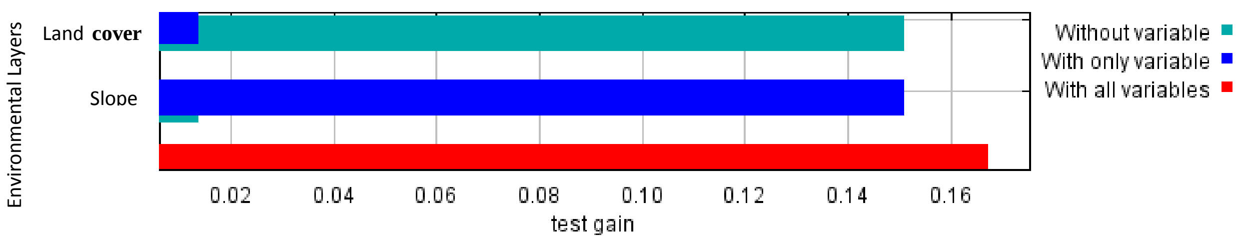

Figure 8 Jackknife test gain chart for slope and land cover

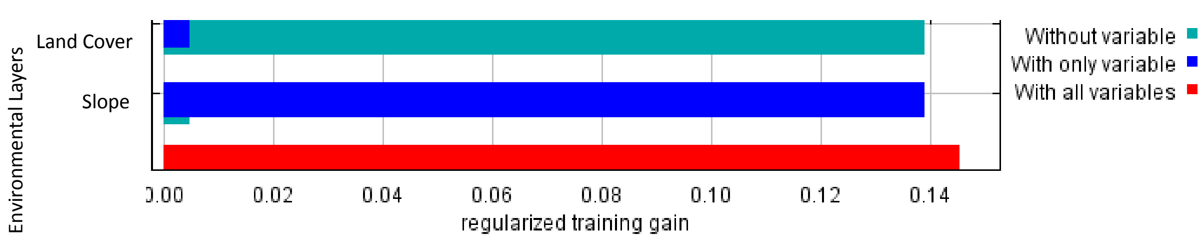

Figure 9 Jackknife regularized training gain chart for slope and land cover

Figures 10 and 11display the most important biophysical and environmental layers during the test gain. The three layers with the highest gain when used in isolation are slope, proximity to mines and primary roads. The layer that decreased the most in test gain was primary roads.

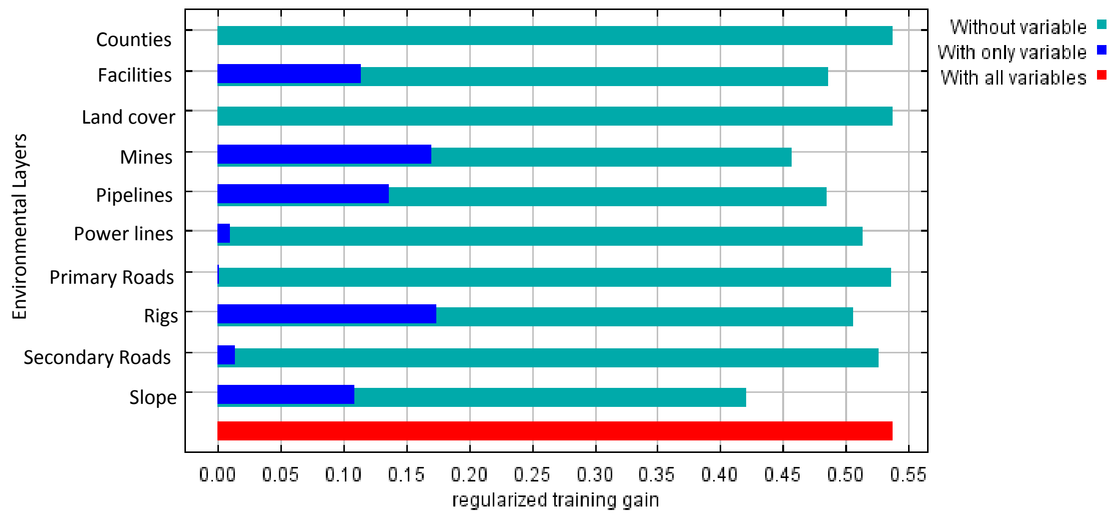

Figure 10 Jackknife regularized training gain chart for biophysical and environmental layers

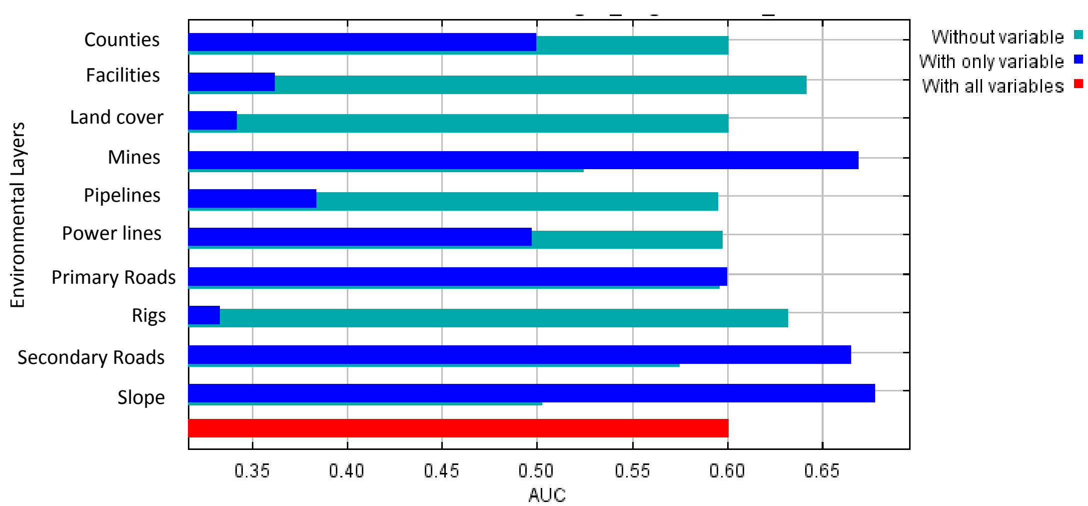

Figure 11 Jackknife test gain for the greater sage-grouse using biophysical and environmental layers

Even though land cover is a very important variable to the greater sage-grouse in the landscape, it did not appear very important when added to the MAXENT model. The large area of sage and gently sloping lands in the two counties reported in Table 6 shows how the influence of the land cover layer was probably subsumed by the slope variable in this particular application.

4.4 Final Habitat Suitability Maps

The following two maps (Figures 12 and 13) show the habitat suitability predicted with the MAXENT model for the greater sage-grouse in Campbell and Converse Counties, WY. The habitat suitability shown in Figure 12 is based on slope and land cover only. Figure 12 represents the habitat for the greater sage-grosue if there were no outside outside influences, such as adverse human activity. Since slope and land cover are two very important natural charactertisics, Figure 12 highlights where suitable habitat is located in the two counties.

Figure 13 depicts habitat suitablity for the greater sage-grouse using slope, land cover, and the envirnmental layers: proximity to rigs, primary and secondary roads, power lines, pipelines, facilities and coal mines. Figure 13 incorporates all the layers in order to understand that not only slope and land cover play a role in habitat suitabilty, but also external factors such as the seven layers previously discussed. Hence, Figure 13 shows how the greater sage-grouse habitat is affected when human activities are introduced into the natural environment. When these elements are added, it greatly lowers the available suitable habitat for the species (Table 7).

The maps can be interperted by understanding that the warm colors red, orange, and yellow are more highly suited for greater sage-grouse habitiat. The cooler colors (i.e., the blues and greens) are less suitable for greater sage-grosue habitat, the warmer colors (i.e. the oranges and reds) are more suitable. The percentages reported in Table 7, on the other hand, show how the areas of suitable habitat decline in both counties – both in an absolute sense and because some high quality habitat was degraded by the aforementioned human activities as well. Table 7 summarizes the suitability estimated with each model based on five equal interval classes. Figures 12 and 13 highlight known, occupied lek sites overlaid on the two suitabilty raster that were created by MAXENT. Campbell County is much more suitable for the greater sage-grouse. The two maps also show that not all of the lek sites fell within the suitable habitat areas predicted by MAXENT, because human influences can override natural features that the species prefer.

Table 7: Percentage of Campbell and Converse Counties combined ranges of suitability scores in the two MAXENT model runs

MAXENT Suitability	**Campbell and Converse Counties Combined**	
	Model 1	**Model 2**
0.0-0.2	5.5%	87%
0.2-0.4	48.0%	6%
0.4-0.6	46.5%	4%
0.6-0.8		2.6%
0.8-1.0		0.4

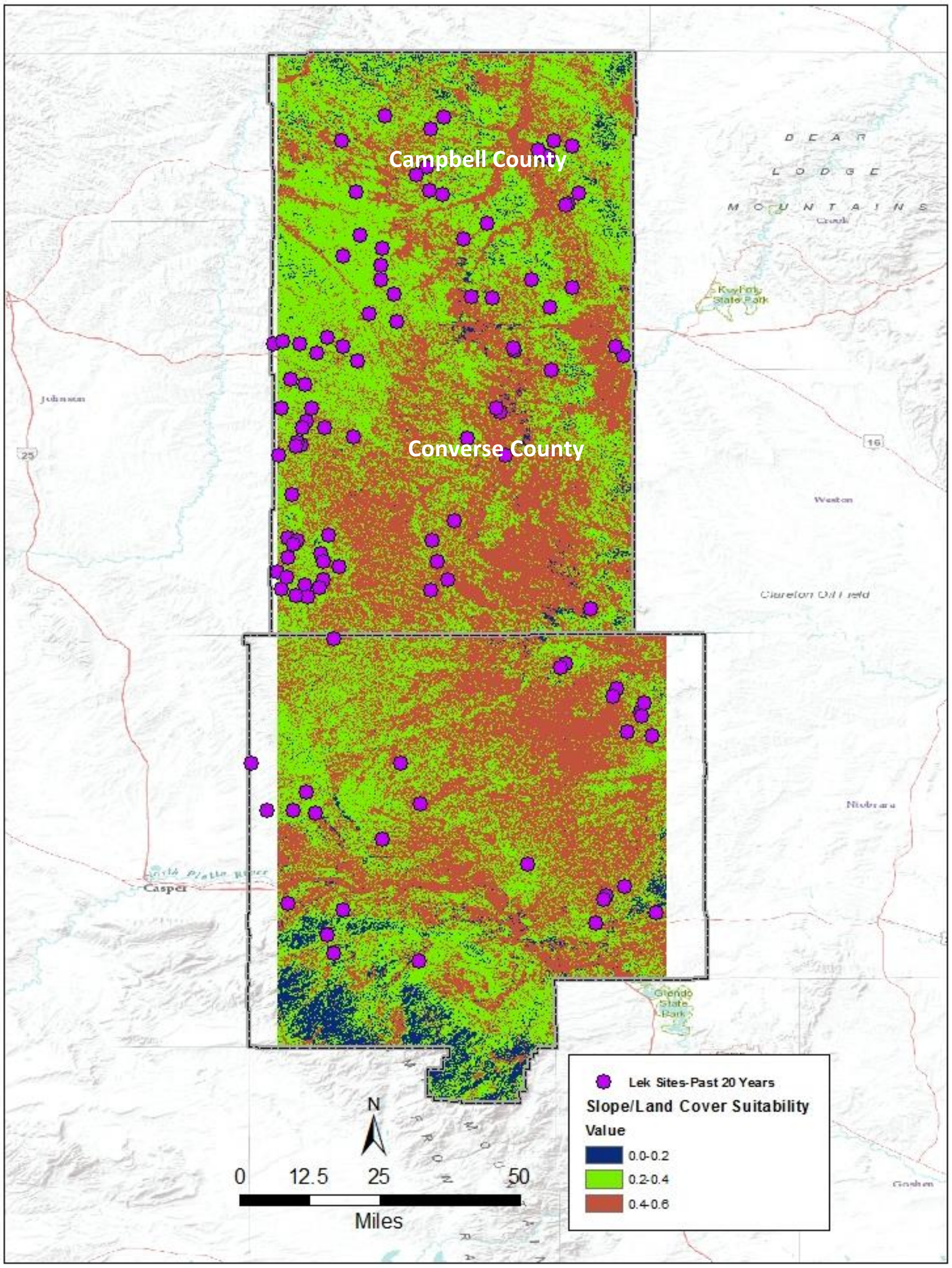

Figure 12 Greater sage-grouse suitability map based on slope and land cover in Campbell and Converse counties with lek sites from past 20 years

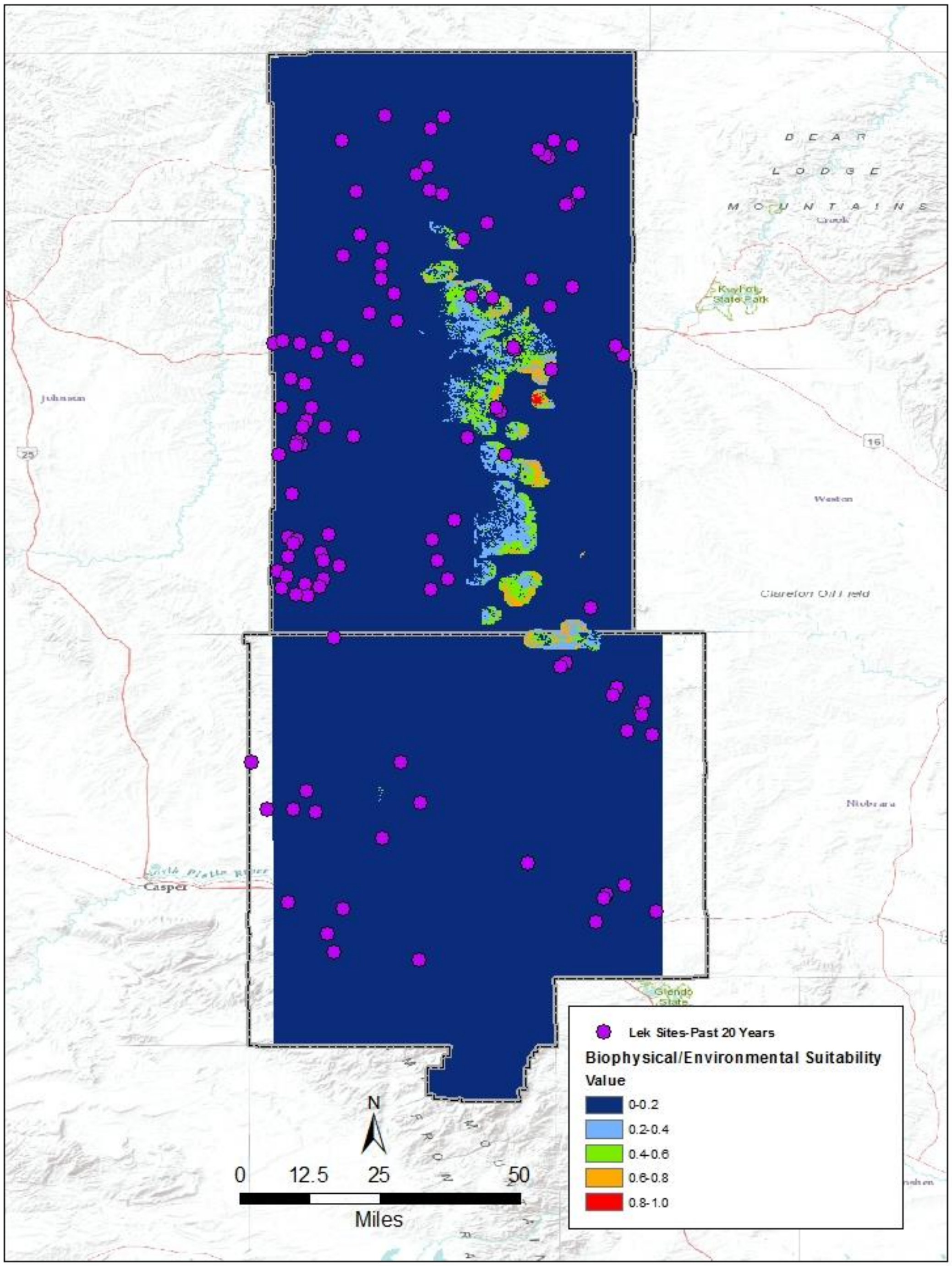

Figure 13 Greater sage-grouse suitability map based on slope, land cover, rigs, facilities, coal mines, power lines, pipeline, primary and secondary road and lek sites from the last 20 years in Campbell and Converse counties

CHAPTER 5: DISCUSSION AND CONCLUSIONS

This chapter considers some broader issues related to the model runs and the spatial distribution of the greater sage-grouse in northeastern Wyoming. The first two sections talk about model strengths and weaknesses and the third section offers some thoughts about future research needs and opportunities.

5.1 Model Strengths

The first model highlighted the two biophysical layers; slope and land cover. The model scored a training AUC rating of 0.651 (Figure 6), which can be considered fair to poor. However, Figure 6, which included seven environmental layers (mines, facilities, primary and secondary roads, pipelines, rigs, and power lines), as well as the two biophysical layers (slope and land cover), scored an AUC rating of 0.714 (Figure 7). This implies that this particular model had better predictive performance than the first one and performed well; however, it greatly reduced the amount of predicted greater sage-grouse habitat in the Powder River basin.

The results of the jackknife test indicated that slope is an important biophysical layer to the greater sage-grouse in the region. The species requires a slope of less than or equal to five percent. Land cover did not play a large role in the results, but this outcome probably occurred because slope and land cover are correlated with one another (Table 6).

Once the environmental layers were added to the biophysical layers rigs and mines were the most important in terms of the training gain. Pipelines and facilities were slightly less important. However, in the test gain model some layers declined in importance. Pipelines, roads, facilities, and power lines all decreased in importance during the test gain model. This may seem like a problem; however, it just means that when the model was run and those layers were tested individually against all the layers, these layers were found to be less important in the test model. The AUC model showed that mines and primary and secondary roads contributed the most to the AUC test gain. This means for the greater sage-grouse that the more human activity, the smaller the area of suitable habitat and the less suitable this habitat is overall.

Results from MAXENT show that suitable habitat was determined based on various biophysical and environmental layers. The findings from the study showed that habitat suitable for the greater sage-grouse can be found in both Campbell and Converse Counties. Figure 7 shows the percentages of suitability for the species. The two counties are somewhat similar in suitable habitat. In Figure 13, a majority of the lek sites fall within suitable areas in the two counties. There are lek sites that are located in less than desirable locations, however species tend to adapt to their surroundings in order to survive.

5.2 Model Limitations

The challenges of detecting the greater sage-grouse species are a possible source of error that could affect the representativeness of the observation data. This could introduce errors because of species movement to new lek site locations.

MAXENT uses inputs that can be changed; there is no set rule on how these inputs should be configured. Based on a tutorial from Colorado State University, guidelines for the settings of MAXENT were suggested. The model used a random test percentage of 25, one for the regularization multiplier, 10,000 for the maximum number of background points, and 15 replicates. These decisions can alter the outcome of the MAXENT model and could possibly limit the applicability of the model in specific settings (Young et al., 2011). Changes could be made to the random test percentage to see if it would alter the model in any way. Also, limiting the number of replicates could possibly alter the outcome. However, after running the model several times and make minor adjustments to the outputs, results similar to those reported in the previous chapter were obtained. Additionally, the choice of environmental layers can also affect how MAXENT determines suitable habitat for species, not just the greater sage-grouse.

5.3 Future Research Directions

The BLM manages large expanses of land in eastern Wyoming and they have developed strategies for conservation and land use plan revisions (BLM, 2015). The Sage-Grouse Implementation Team (SGIT) released an Executive Order in August of 2008 that directed state agencies to work to maintain and enhance greater sage-grouse habitat in Wyoming. These areas constituted Wyoming's Core Area Strategy (CAS). Updates were prepared in 2010 and 2011 and further clarification was requested by Governor Dave Freudenthal, when he took office in November, 2012. The CAS addresses the threats to the greater sage-grouse (habitat loss and fragmentation and insufficient regulatory mechanisms), and this new strategy is being implemented across the state under the guidance of a state/federal interagency team of specialists (Wyoming Game and Fish Department, 2012).

The U.S. Agricultural Secretary, Tom Vilsack, recently announced plans for his agency to allocate $200 million over the next three years for programs to protect the greater sage-grouse in the News Sentinel. These funds could double the acreage of the greater sage-grouse to 8 million acres. The reason this species is so important is because it is an umbrella species. Many other species depend on its survival in the west (pronghorn, elk, mule deer, native trout, and nearly 200 migratory and resident bird species). Another important reason the greater sage-grouse is highly important is because it covers many acres spread across numerous states.

Conservation planning is a continuing effort in Wyoming for the greater sage-grouse. It involves multiple agencies who have been working to raise funds and to implement local sage-grouse conservation projects. Incentives to insure management actions on private and public lands will continue in a manner that in ecologically, economically, and culturally sustainable (Wyoming Game and Fish Department, 2012).

MAXENT can also play a role in helping state and federal agencies determine where suitable habitats are located for the greater sage-grouse as well as other species struggling to find adequate habitat. Policy makers using this tool would have more information regarding the greater sage-grouse, or other species, to make better informed decisions as to what areas would need more funding for conservation.

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