An Evaluation of Habitat Suitability Modelling Using the Greater Sage Grouse (*Centrocercus urophasianus*) as a Case Study

Benjamin C. Colteaux[1]

[1] *Integrative Life Sciences, Virginia Commonwealth University, Richmond, VA 23284, USA*

1. Species Introduction

The greater sage grouse (*Centrocercus urophasianus*), known from this point forward as sage grouse, is an avian species native to thirteen U.S. states. The sage grouse has seen population reductions across its range and total extirpation from 2 states in its original range (Montana, 2014). Populations have experienced reductions due to habitat destruction, urbanization, and environmental toxicity (Connelly et al., 2004; Holloran et al., 2005). The states hosting the largest populations of sage grouse include Wyoming, Idaho, Nevada, Oregon and Montana. Here I focus on the state of Montana and attempt to identify, based on the metrics from current established populations, habitats across the state which would be suitable candidates for introduction of sage grouse populations and compare those to known sage grouse populations to test the power of this approach.

1.1 Project Goals

The main goal of this project was to take skills learned in ENVS 691 and apply them to solve an ecological problem. I decided to use a species, the sage grouse, and a state, Montana, which I had no prior knowledge of in order to fully test these skills. I wanted to create not one but two different habitat suitability models, based off what the Montana heritage program considers the core habitat for the sage grouse, and test them against known sage grouse population locations. As I had no prior species knowledge, outside of background reading, I used the core habitat to dictate the layer thresholds. Using those thresholds I wanted to design two suitability models, 1 binary and 1 weighted. With two models in hand I would first compare them to each other to test if making the second model was necessary, and then compare them both to the known sage grouse population distributions to test the predictive ability of the models I created. The secondary goal of this project was to create a project which could be added to my portfolio and website to show my skillset to future employers.

2. Methods

2.1: Data

All data incorporated into this project came from sources available in the public domain. In order to create a thorough habitat suitability model I included the following layers: The sage grouse core habitat, maximum and minimum temperatures covering the years 1971 to 2000, precipitation covering the years 1971 – 2000, population density, land cover, elevation, and managed areas. The managed areas layer was created by merging areas managed by private conservation, Montana managed areas, and Native American reservations. The minimum and maximum temperature layer represents the average daily high and low temperature for every day, for the thirty year span indicated. Montana county boundaries, major cities and known habitat were included in the overall map project as reference and are not factored into the suitability model. For a listing of all layers, their formats, and sources please see Table 1.

2.2 Data Processing

All habitat suitability models were created, and all analyses run, using ArcGIS 10.2 (ESRI, 2013). In order to make suitable comparisons datasets from 2000 were used, as that was the most recent year which was available across all layers. Cell size was standardized to $1000m^2$. In order to create the habitat suitability models, which make use of the raster calculator tool, it was necessary first to convert all polygon layers (Table 1) to raster layers using the polygon to raster conversion tool. From there the area of each raster layer that fell within the core habitat was isolated, using the extract by mask tool within spatial analyst, in order to establish acceptable population thresholds for each layer (Table 2). These thresholds were then applied to the full raster for each variable, using raster calculator, to provide those areas in the state that meets those individual thresholds as indicated by a Binary output of 1. For example, the full minimum temperature layer was masked using the sage grouse core area polygon. The result of the mask was the isolation of those minimum temperatures that are acceptable based on that core area. The model structure created for these processes is shown in Figure 1.

2.3 Binary Suitability Model

In order to create a binary model it was necessary to determine, given the thresholds of each layer, areas that were suitable and unsuitable. This was achieved by creating a separate Binary raster for each variable where 1 indicated suitable habitat and 0 indicated unsuitable habitat. All Binary layers, except land cover, were created using the “&” function within raster calculator in order to isolate a range of values. As land cover is not a continuous range of numbers but a set of specific numbers corresponding to a particular land cover designation, the “+” function was used. Once all of the Binary layers were complete raster calculator was again used to combine the individual Binary rasters into one master

Binary raster. The resulting raster showed the areas of the state where the habitat thresholds of all variables were met thus indicating areas that were suitable (1) or unsuitable (0) to house sage grouse populations.

2.4 Weighted Suitability Model

Using the Binary raster outputs for each variable, from the binary suitability model, a weighted suitability model was created. Each output raster was given a relative weight determined by the range of each value from the core habitat. For example, as the accepted density thresholds from the core area made up less than one percent of all density levels for the state it was given the highest influence, that is sage grouse are most sensitive to the effects of human population density. The weighted suitability equation used, within raster calculator, is given in equation (a).

("landcover.tif" * .01) + ("precip.tif" * .01) + ("mintemp.tif" * .12) + ("maxtemp.tif" * .06) + ("elevation.tif" * .20) + ("density.tif" * .50) (a)

The resulting raster created ranked the area of the state on a gradient scale from 0 (unsuitable) to 1 (suitable). Unlike the binary model this method produced a range of values. The weighted model was re-run using the weighted overlay tool within spatial analyst. As landcover and precipitation had very little influence in the first weighted model those variable were removed from this model run, and the model parameters are shown in Figure 2. The resulting raster ranked the areas of the state, in regards to suitability, from 1 (unsuitable) to 8 (Ideal) by 1 (normally there are 9 values but as the model had no output for rank 5 the range was concatenated).

2.5 Post-Processing

First, the areas of the state known, as of January 2015, to contain sage grouse populations were overlayed on the two habitat suitability model outputs to test the relative strength of each approach. Second, a principal components analysis was run to analyze the model variables against one another.

3. Results

The results from the binary suitability model indicated that 81% of the state was unsuitable to house sage grouse populations (Figure 3). The results from the weighted suitability model indicated that less than 1% of the state was fully unsuitable and that 19% of the state was ideally suited to house sage grouse populations (Figure 4). The remaining areas, in the weighted model, fell somewhere between unsuitable (1) and ideal (8) (Figure 5). The overlays of known sage grouse habitat with each model is shown in Figure 6. The results of the accumulative principal components analysis are given below.

Layer	EigenValue	Percent of EigenValues	Accumulative of EigenValues
Minimum Temperature (˚F)	0.3289	64.7012	64.7012
Elevation (Feet)	.10074	19.8185	84.5196
Maximum Temperature (˚F)	.069727	13.7163	98.2360
Precipitation (Inches)	.007875	1.5457	99.7816
Land Cover	.000654	0.1287	99.9104
Population Density (sqmi)	.000455	0.0896	100.00

4. Conclusions

When visual comparisons are made between maps created by the binary and weighted models the difference between the two approaches is stark (Figure 6). As the binary model only gives two values, either all parameters are met or not all parameters are met, there is no way to tell what areas may not be ideally suitable but still able to house sage grouse populations. When the known population is overlayed on the binary model output we see that the majority of known populations fall within areas the binary model considers unsuitable. Conversely, the weighted model allows the user to see those areas of the state that, while not ideally suitable, could potentially house populations. Once overlayed with the known distributions the strength of the weighted model is apparent. All of the know areas, with very tiny exceptions, now fall within areas which ranked in the upper half (5-8) of the weighted model rankings. That is, all of the known sage grouse populations fall in either ideal or near ideal conditions. In this case study the weighted suitability model greatly outperformed the binary suitability model. The accuracy of the weighted approach might increase even further if in depth biological data were used to determine the influence of each of the variables used. As it is, the weighted suitability modeling approach could be of great use to scientists trying to predict suitable habitats or at the very least used to eliminate those areas that are thoroughly unsuitable thereby reducing the costs of investigating those areas.

The findings from this project are available in a step by step format on my website: www.bencolteaux.com

Acknowledgements: I would like to thank the following organizations who contributed data to this project: Montana State Library, PRISM at Oregon State, Oregon Climate Service, Montana Heritage, and Montana Fish, Wildlife and Parks. I would also like to thank William Shuart and Jennifer Ciminelli for their continued support and patience.

Works Cited

Connelly, J.W., Knick, S.T., Schroeder, M.A., Stiver, S.J., 2004. Conservation assessment of greater sage-grouse and sagebrush habitats.

Holloran, M.J., Heath, B.J., Lyon, A.G., Slater, S.J., Kuipers, J.L., Anderson, S.H., 2005. Greater Sage-Grouse Nesting Habitat Selection and Success in Wyoming. J. Wildl. Manage. 69, 638–649. doi:10.2193/0022-541X(2005)069[0638:GSNHSA]2.0.CO;2

State of Montana, 2014. Greater Sage-Grouse - Centrocercus urophasianus [WWW Document]. URL http://fieldguide.mt.gov/speciesDetail.aspx?elcode=ABNLC12010 (accessed 2.12.15).

Figure Captions

Figure 1. Modelling layout for the process of converting shapefiles to raster layers for model processing and subsequent masking by the sage grouse core habitat layer to establish variable thresholds for use in creating a binary suitability model.

Figure 2. Screen capture of the weighted overlay tool within spatial analyst and ArcGIS 10.2. Screenshot shows the influence percentage assigned to each variable.

Figure 3. Binary habitat suitability model output. State of Montana is shown, with the largest city per county. Areas in green indicate predicted suitable habitat and areas in grey indicate predicted unsuitable habitat.

Figure 4. Weighted habitat suitability model output. State of Montana is shown, with the largest city per county. Rankings range from red (rank 1 – unsuitable predicted habitat) to dark green (rank 8 – ideal predicted habitat).

Figure 5. Count of cells ($1000m^2$) that fall within each rank of the weighted habitat suitability model output. Colors correspond to legend colors indicating rank in Figure 4. All 9 ranks given, including rank 5 which contains no counts, rather than concatenated 1 – 8 range.

Figure 6. Output of both the binary and weighted suitability is shown. The gold hash-marking indicates areas of Montana that are known to contain sage grouse populations, as of January 2015. The largest city per county is also shown.

Figure 1.

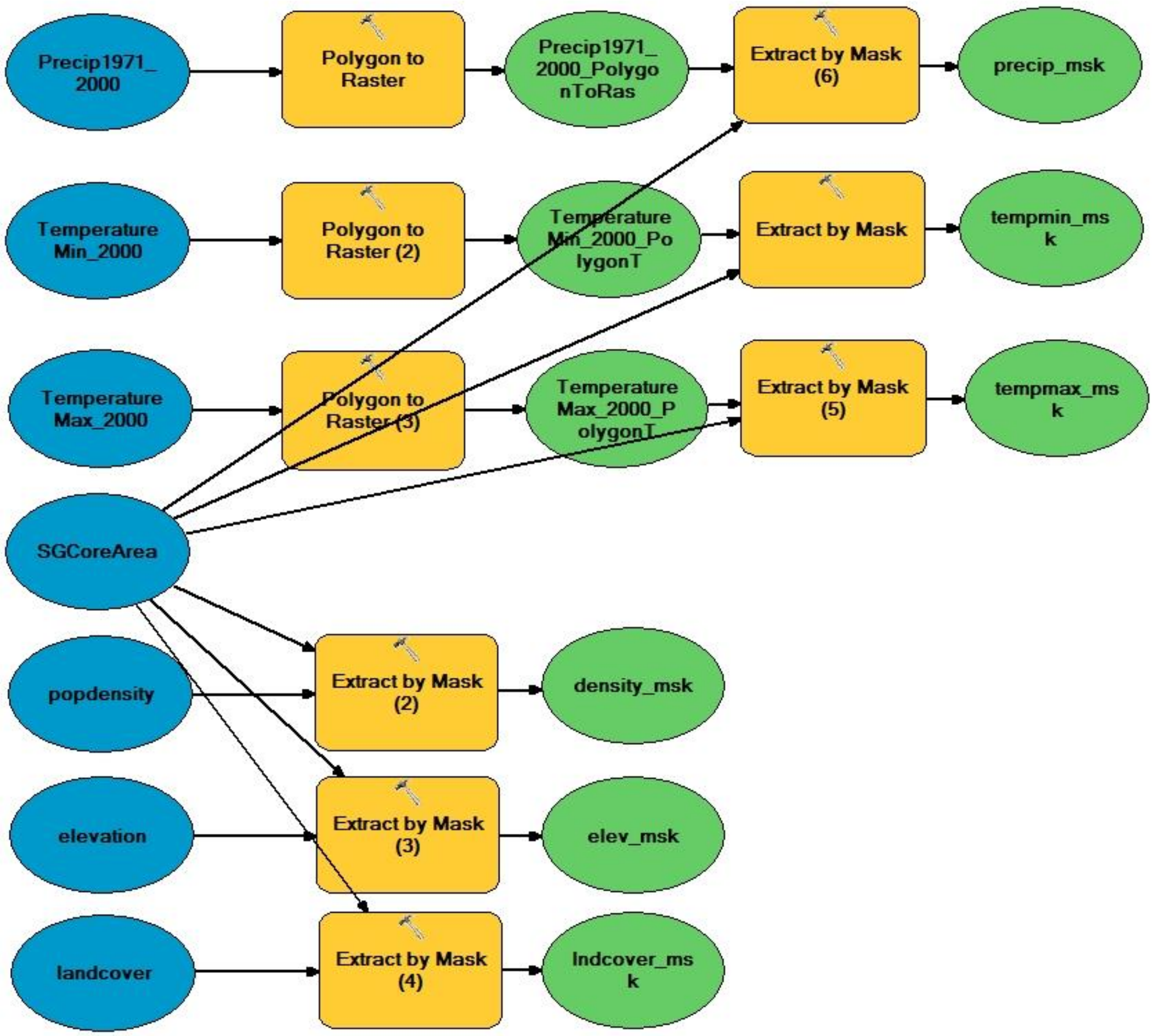

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Figure 2.

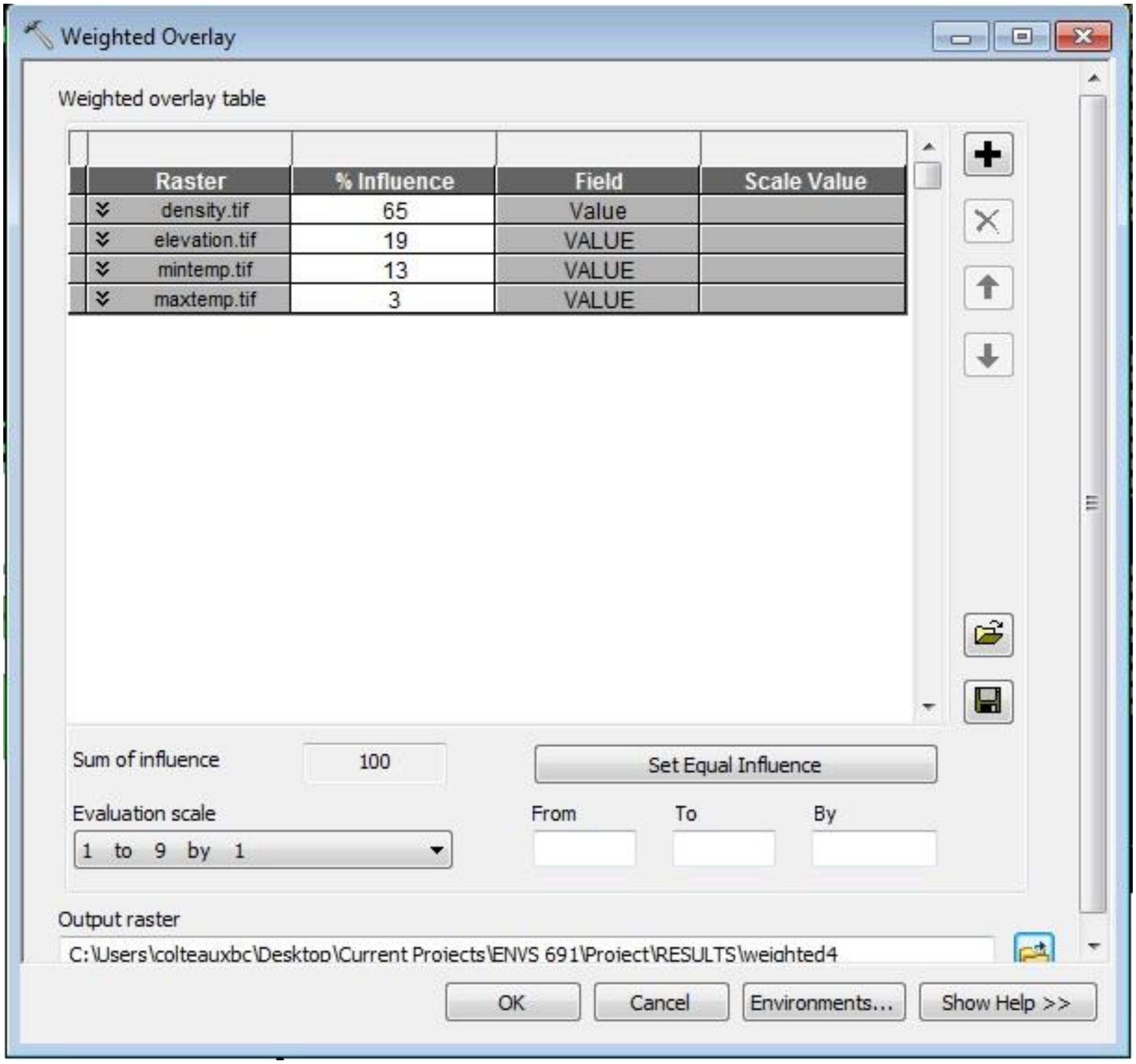
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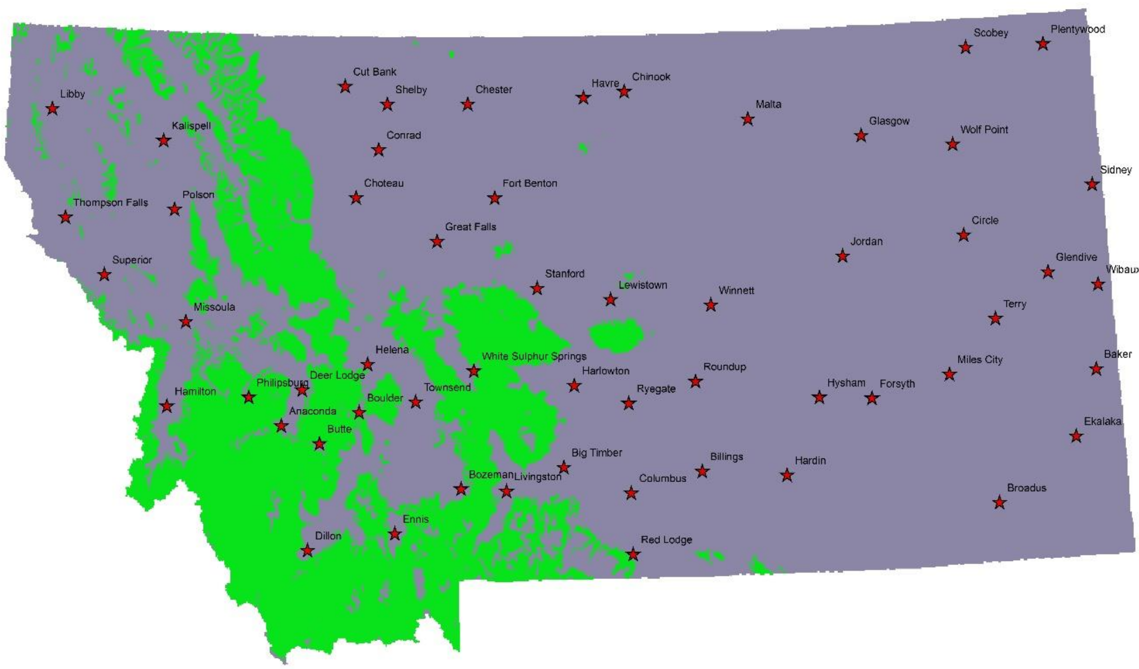
Figure 3.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Winnett
Missoula
Terry
Helena
White Sulphur Springs
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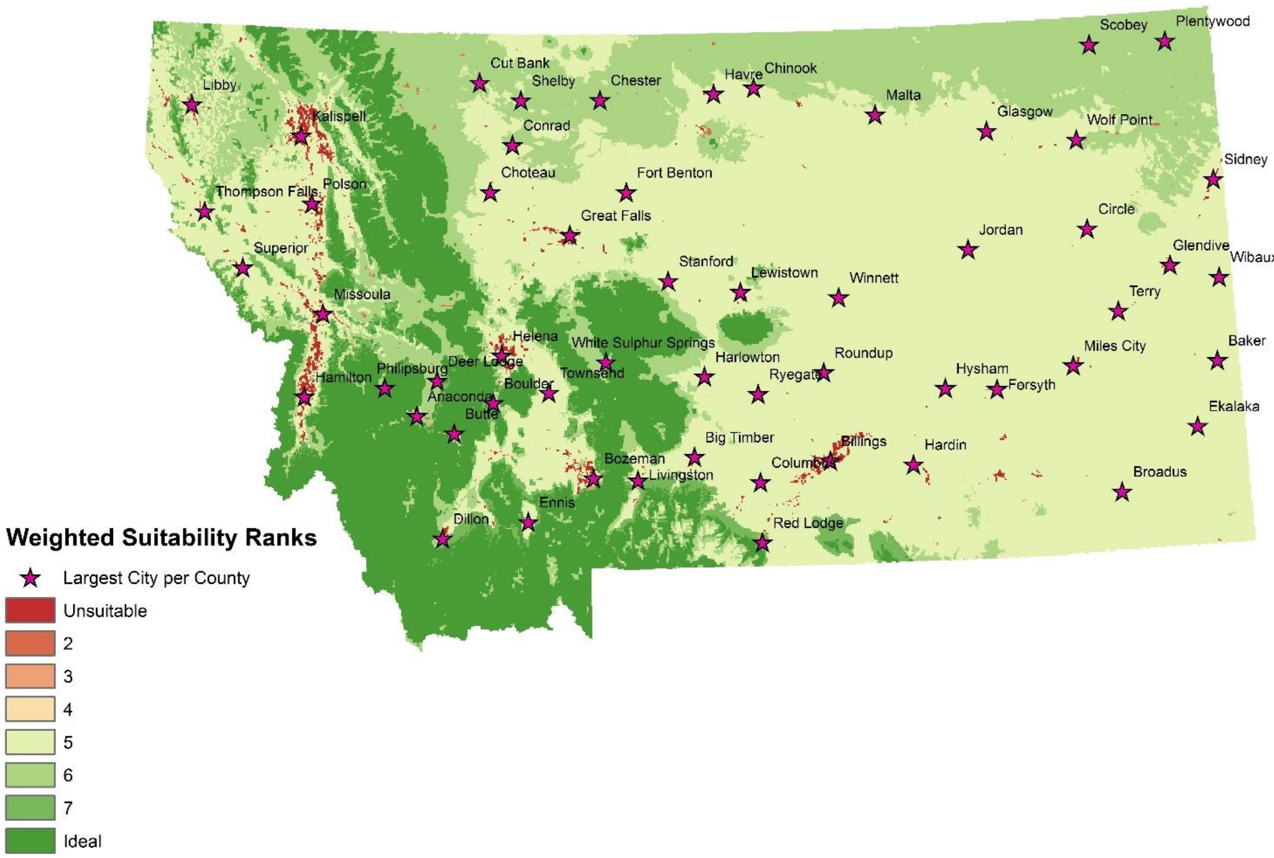
Figure 4.



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Big Timber
Billings
Hardin
Bozeman
Columbus
Livingston
Broadus
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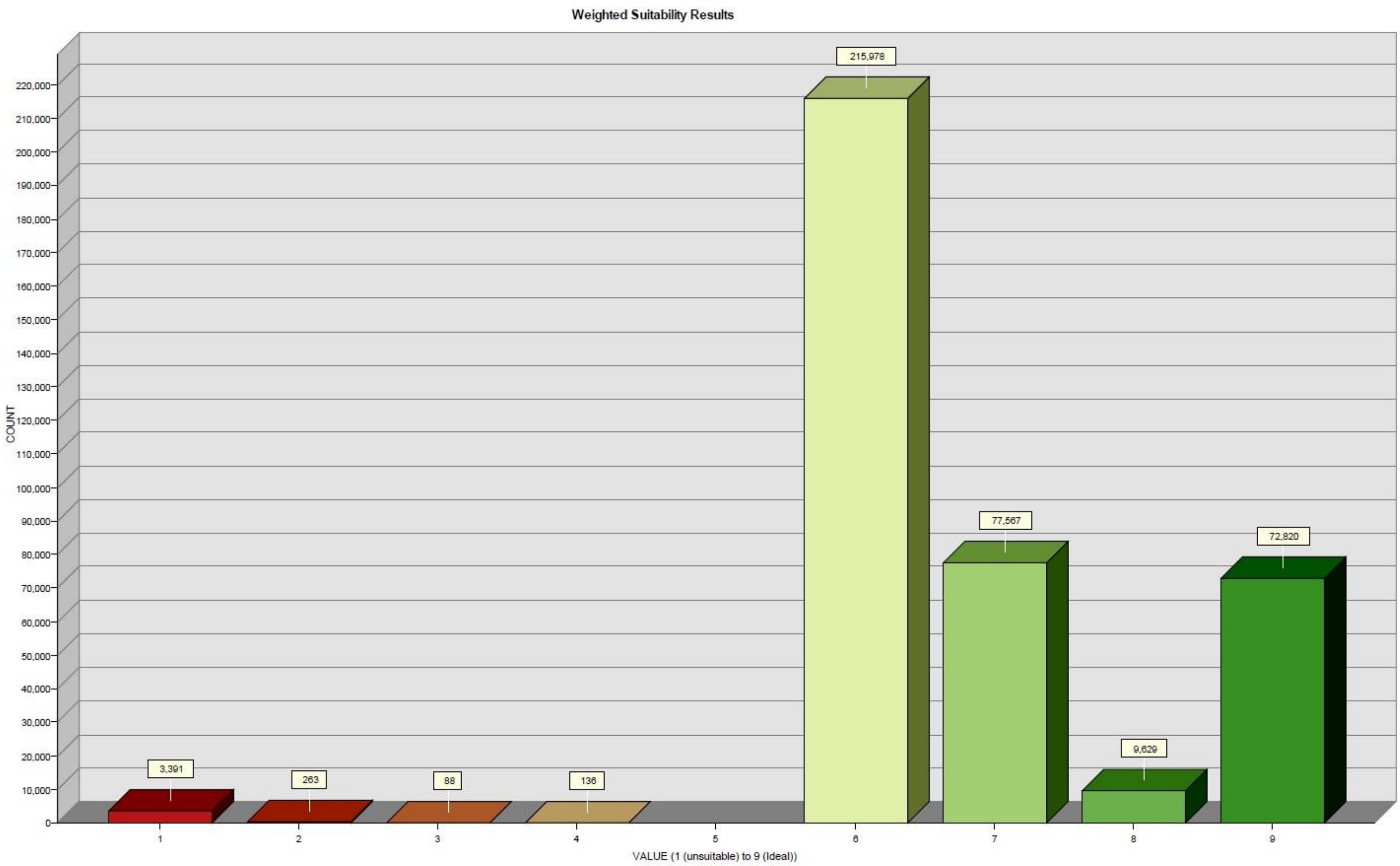
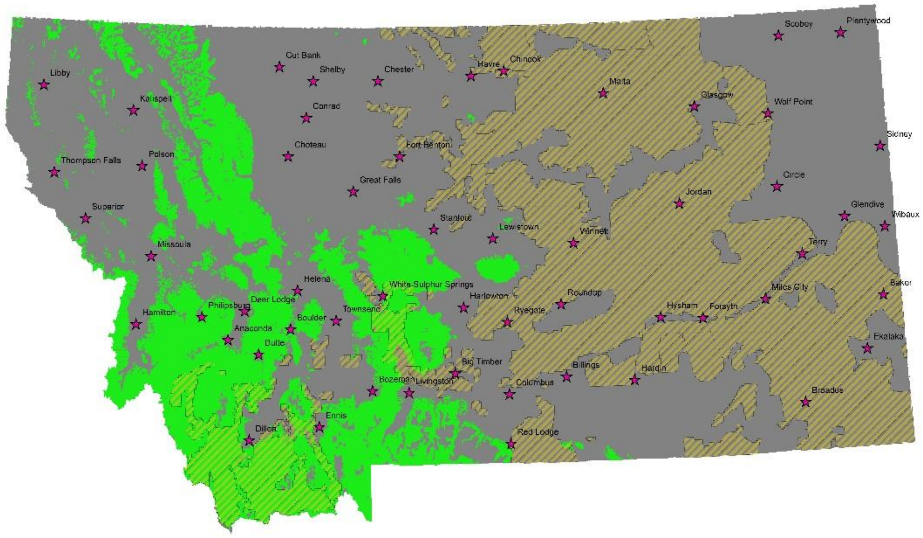
Weighted Suitability Ranks
Largest City per County
Unsuitable
2
3
4
5
6
7
Ideal

Figure 5.



Weighted Suitability Results
COUNT
VALUE (1 (unsuitable) to 9 (Ideal))
3,391
263
88
136
215,978
77,567
9,629
72,820

Figure 6.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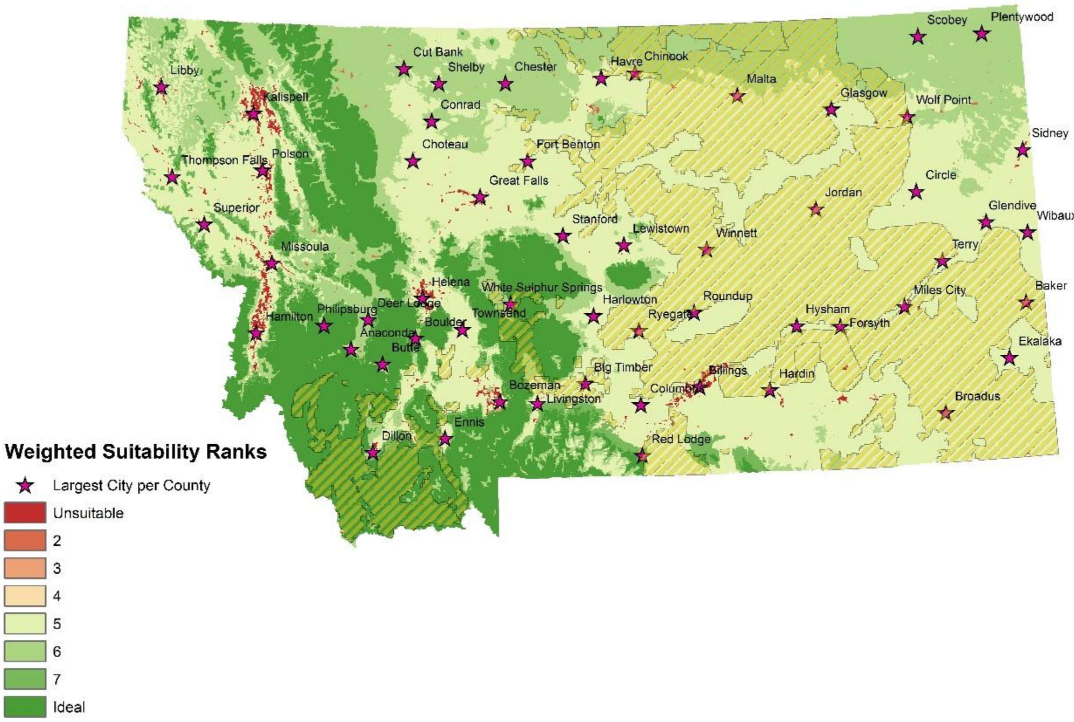
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Weighted Suitability Ranks
Largest City per County
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3
4
5
6
7
Ideal

Table 1.

List of all layers used in model creation or analysis, their Datum/Projection, File Type and source.

Layer Name	DATUM/PROJECTION	Type	Source
Sage Grouse Core Habitat	LCC/NAD83	Shape file	Montana Fish, Wildlife & Parks
Montana County Boundaries	LCC/NAD83	Shape file	Montana State Library
Temperature Max (1971-2000)	LCC/NAD83	Shape file	PRISM Oregon State
Temperature Min (1971 -2000)	LCC/NAD83	Shape file	PRISM Oregon State
Precipitation (1971 – 2000)	LCC/NAD83	Shape file	Oregon Climate Service
Major Cities	LCC/NAD83	Shape file	Montana State Library
Known Population Range	LCC/NAD83	Shape File	Montana Fish, Wildlife & Parks
Population Density	NAD83/NAD83UTM12N	Raster	MT State Library/TIGER
Land Cover	NAD83	Raster	Montana State Library
Elevation	NAD83	Raster	National Elevation Dataset

Table 2.

List of each variable (layer) the range of values throughout Montana and the range of values (Suitability Thresholds) found in the sage grouse core habitat.

Variable	Range	Suitability Thresholds
Land Cover	17 values	15 values
Minimum Temperature (˚F)	10 - 38	19 - 29
Maximum Temperature (˚F)	32 - 64	41 - 57
Precipitation (Inches)	1 - 26	1 - 23
Elevation (Feet)	1883 - 11610	5287 - 9091
Population Density (sqmi)	0 - 79058.8	0 - 31.7