Gray Wolf (*Canis lupus*)
Predicted Suitable Habitat Modeling

**Distribution Status:** Resident Year Round
**State Rank:** S4
**Global Rank:** G5

**Modeling Overview**

**Created by:** Braden Burkholder  
**Creation Date:** November 2, 2017  
**Evaluator:** Braden Burkholder  
**Evaluation Date:** November 2, 2017

**Inductive Model Goal:** To predict the distribution and relative suitability of general year-round habitat for Gray Wolf at large spatial scales across its presumed range in Montana.

**Inductive Model Performance:** The model appears to adequately reflect the distribution of general year-round habitat suitability for Gray Wolf at larger spatial scales across its presumed range in Montana. Evaluation metrics indicate a good model fit and the delineation of habitat suitability classes is well supported by the data, although optimal habitat is not predicted based on the strength of the selection patterns estimated by this modeling process. For a habitat generalist, this is not surprising.

**Deductive Model Goal:** To represent the ecological systems commonly and occasionally associated with Gray Wolf year-round, across its presumed range in Montana.

**Deductive Model Performance:** Ecological systems that Gray Wolf is commonly and occasionally associated with overpredict the amount of suitable habitat across its presumed range in Montana.

**Suggested Citation:** Montana Natural Heritage Program. 2017. Gray Wolf (*Canis lupus*) predicted suitable habitat models created on November 2, 2017. Montana Natural Heritage Program, Helena, MT. 16 pp.

Inductive Modeling

Model Limitations and Suggested Uses
This model is based on statewide biotic and abiotic layers originally mapped at a variety of spatial scales and standardized to 90×90 meter raster pixels. The spatial accuracy of the training and testing data are varied (typically 20-400 meters) and may result in additional statistical noise in the model. As a result, model outputs may not be appropriate for use on smaller areas or at fine spatial scales. Model outputs should not typically be used for planning efforts on land areas smaller than one quarter of a public land survey system (PLSS) section (<64 hectares) and model outputs for some species may only be appropriate for broader regional level planning efforts. Model outputs should not be used in place of on-the-ground surveys for species, and wildlife and land management agency biologists should be consulted about the value of using model output to guide habitat management decisions for regional planning efforts or local projects. See Suggested Contacts for State and Federal Natural Resource Agencies attached to this document.

Inductive Model Methods

Modeling Process
Presence-only data were obtained from Montana Natural Heritage Program Databases, which serve as a clearinghouse for animal and plant observation data in Montana. These data were then filtered to ensure spatial and temporal accuracy and to reduce spatial auto-correlation (summarized in Table 1). The spatial extent of this model was limited to the presumed geographic range of the species, by season when applicable, in order to accurately assess potentially available habitat.

We then used these data and 19 statewide biotic and abiotic layers (Table 2) to construct the model using a maximum entropy algorithm employed in the modeling program Maxent (Phillips et al. 2006, Ecological Modeling 190:231-259). Entropy maximization modeling functions by calculating constraints and then applying the constraints to estimate a predicted distribution. The mean and variance of the environmental variables at the training data locations are used to estimate the constraint distributions. Maxent requires that the final predicted distribution fulfills these constraints. Maxent avoids overfitting models to the training data by “regularizing” or relaxing the constraints so that modeled distributions only have to be close to, rather than exactly equal to, the constraint distributions (Elith et al. 2011, Diversity and Distributions 17:43-57).

Maxent fits a model by assuming the predicted distribution is perfectly uniform in geographic space and moves away from this distribution only to the extent that it is forced to by the constraints. Constrained by training data, Maxent successively modifies the coefficients for each environmental variable via random walk, accepting the modified coefficient if it increases the gain. Gain is a measure of the closeness of the model concentration around the presence samples that is similar to goodness of fit in generalized linear models. The random walk of coefficients continues until either the increase in the gain falls below a set threshold or a set maximum number of iterations are performed. The gain value at the end of a model run indicates the likelihood of suitability of the presence samples relative to the likelihood for random background points. The overall gain associated with individual environmental variables can be used as a measure of the relative importance of each variable (Merow et al. 2013, Ecography 36:1058-1069).
We employed a k-folds cross validation methodology, in this case using ten folds for model training and validation (Elith et al. 2011). Each fold consists of 90% of the data designated for training and 10% of the data reserved for testing. Each record is used for training nine times and testing once. Ten models are estimated and averaged to produce the final model presented here.

Model Outputs and Evaluation
The initial model output is a spatial dataset of continuous logistic values that ranges from 0-1 with lower values representing areas predicted to be less suitable habitat and higher values representing areas predicted to be more suitable habitat (Figures 3 & 5-7). The standard deviation in the model output across the averaged models is also calculated and plotted as a map to examine spatial variance of model output (Figure 4). If enough observations were available to train and evaluate the models, the continuous output is reclassified into suitability classes - unsuitable, low suitability, moderate suitability, and high suitability (Figures 8 & 9). Thresholds for defining suitability classes are presented and described below (Table 4).

In addition to the map of spatial variance in model output, we also evaluated the output of the Maxent model with absolute validation index (AVI) (Hirzel et al. 2006, Ecological Modelling 199:142-152) and deviance (Phillips and Dudik 2008, Ecography 31: 161-175). These metrics are described below in the results (Table 5). Area under the curve (AUC) values are also displayed for reference, but are not used for evaluation (Lobo et al. 2008, Global Ecology and Biogeography 17:145-151). Finally, a deviance value was calculated for each test data observation as a measure of how well model output matched the location of test observations and this was plotted with larger symbols indicating larger deviance (Figure 6). In theory, everywhere a test observation was located, the logistic value should have been 1.0. The deviance value for each test observation is calculated as -2 times the natural log of the associated logistic output value.

Table 1: Model Data Selection Criteria and Summary

<table>
<thead>
<tr>
<th>Location Data Source</th>
<th>Montana Natural Heritage Program Databases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Number of Records</td>
<td>1,865</td>
</tr>
<tr>
<td>Location Data Selection Rule 1</td>
<td>Records with &lt;= 6400 meters of locational uncertainty</td>
</tr>
<tr>
<td>Number of Locations Meeting Selection Rule 1</td>
<td>1,047</td>
</tr>
<tr>
<td>Location Data Selection Rule 2</td>
<td>No overlap in locations within 1600 meters in order to avoid spatial autocorrelation</td>
</tr>
<tr>
<td>Observation Records used in Model (Locations Meeting Selection Rules 1 &amp; 2)</td>
<td>381</td>
</tr>
<tr>
<td>Season Modeled</td>
<td>Year-round</td>
</tr>
<tr>
<td>Number of Model Background Locations</td>
<td>23,603</td>
</tr>
</tbody>
</table>
Table 2: Environmental Layer Information

<table>
<thead>
<tr>
<th>Layer</th>
<th>Identifier</th>
<th>Original Scale</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land Cover</td>
<td>catesys</td>
<td>30m</td>
<td>Categorical. Landcover classes (25) from the 2016 Montana Spatial Data Infrastructure Land Cover Framework; Level 2 classes used with a few minor changes including removal of linear and point features: Alpine Grassland and Shrubland, Alpine Sparse and Barren, Conifer-dominated Forest and Woodland (mesic-wet), Conifer-dominated Forest and Woodland (xeric-mesic), Deciduous dominated forest and woodland, Mixed deciduous/coniferous forest and woodland, Lowland/Prairie Grassland, Montane Grassland, Agriculture, Introduced Vegetation/Pasture/Hay, Developed, Mining and Resource Extraction, Wetland or Marsh, Floodplain and Riparian, Open Water, Wet meadow, Harvested Forest, Insect-Killed Forest, Introduced Vegetation, Recently burned, Deciduous Shrubland, Sagebrush Steppe or Desert Scrub, Sagebrush or Saltbush Shrubland, Bluff/Badland/Dune, Cliff/Canyon/Talus. <a href="http://geoinfo.msl.mt.gov/msdi/land_use_land_cover">Link</a></td>
</tr>
<tr>
<td>Soil Order</td>
<td>catsoilord</td>
<td>Vector</td>
<td>Categorical. Major soil orders (7) as defined by USDA based on STATSGO2 general statewide soil maps, along with non-soil (Rock, Water) classifications: Entisols, Inceptisols, Aridisols, Molisols, Alfisols, Andisols, and Vertisols. <a href="http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx">Link</a></td>
</tr>
<tr>
<td>Elevation</td>
<td>contelev</td>
<td>=10m</td>
<td>Continuous. Elevation in meters above mean sea level. <a href="https://www.sciencebase.gov/catalog/item/4f70aa9f4eb058caae3f8de5">Link</a></td>
</tr>
<tr>
<td>Aspect (East-West)</td>
<td>contewasp</td>
<td>=10m</td>
<td>Continuous. Aspect of slopes, ranging from 1 (east) to -1 (west). <a href="https://www.sciencebase.gov/catalog/item/4f70aa9f4eb058caae3f8de5">Link</a></td>
</tr>
<tr>
<td>Aspect (North-South)</td>
<td>contnsasp</td>
<td>=10m</td>
<td>Continuous. Aspect of slopes, ranging from 1 (north) to -1 (south). <a href="https://www.sciencebase.gov/catalog/item/4f70aa9f4eb058caae3f8de5">Link</a></td>
</tr>
<tr>
<td>Slope</td>
<td>contslope</td>
<td>=10m</td>
<td>Continuous. Percent slope (x100) of landscape. <a href="https://www.sciencebase.gov/catalog/item/4f70aa9f4eb058caae3f8de5">Link</a></td>
</tr>
<tr>
<td>Ruggedness</td>
<td>contvrm</td>
<td>=10m</td>
<td>Continuous. Vector ruggedness measure (0 to 1). <a href="https://www.sciencebase.gov/catalog/item/4f70aa9f4eb058caae3f8de5">Link</a></td>
</tr>
<tr>
<td>Summer Solar Radiation</td>
<td>contsumrad</td>
<td>=10m</td>
<td>Continuous. Solar radiation (WH/m²) for the day of the summer solstice. <a href="https://www.sciencebase.gov/catalog/item/4f70aa9f4eb058caae3f8de5">Link</a></td>
</tr>
<tr>
<td>Winter Solar Radiation</td>
<td>contwinrad</td>
<td>=10m</td>
<td>Continuous. Solar radiation (WH/m²) for the day of the winter solstice. <a href="https://www.sciencebase.gov/catalog/item/4f70aa9f4eb058caae3f8de5">Link</a></td>
</tr>
<tr>
<td>Annual NDVI</td>
<td>contndvi</td>
<td>900m</td>
<td>Continuous. Normalized Difference Vegetation as a measure of yearly mean greenness from the MODIS Terra satellite. <a href="">Link</a></td>
</tr>
<tr>
<td>Annual Precipitation</td>
<td>contprecip</td>
<td>=800m</td>
<td>Continuous. Average annual precipitation (mm) for 1981-2010. <a href="http://www.prism.oregonstate.edu/normal/">Link</a></td>
</tr>
<tr>
<td>Percent Winter Precipitation</td>
<td>contwinpcp</td>
<td>=800m</td>
<td>Continuous. Average percent (0 to 1) of the total annual precipitation that occurs during winter (Nov-Apr) for 1981-2010. <a href="http://www.prism.oregonstate.edu/normal/">Link</a></td>
</tr>
<tr>
<td>Max Summer Temp</td>
<td>conttmax</td>
<td>800m</td>
<td>Continuous. Average maximum temperature (°C) in July for 1981-2010. <a href="">Link</a></td>
</tr>
<tr>
<td>Min Winter Temp</td>
<td>conttmin</td>
<td>800m</td>
<td>Continuous. Average minimum temperature (°C) in January for 1981-2010. <a href="">Link</a></td>
</tr>
<tr>
<td>Degree Days</td>
<td>contddays</td>
<td>800m</td>
<td>Continuous. Average annual total of degree days (°F) above 32°F for 1981-2010. <a href="http://services.cfc.umd.edu/argcis/rest/services/Atlas/Temperature_CropDegreeDays32F/ImageServer">Link</a></td>
</tr>
<tr>
<td>Distance to Stream</td>
<td>contstrmed</td>
<td>vector</td>
<td>Continuous. Distance to major streams in meters, based on major streams identified in TIGER files or USGS topographic maps (Stream_Lake_1993 dataset). <a href="http://ftp.geoinfo.msi.mt.gov/Data/Spatial/NonMSDI/Shapefiles/">Link</a></td>
</tr>
<tr>
<td>Distance to Forest Cover</td>
<td>contfrsted</td>
<td>30m</td>
<td>Continuous. Distance to any forest land cover type in meters. <a href="http://geoinfo.msl.mt.gov/msdi/land_use_land_cover">Link</a></td>
</tr>
</tbody>
</table>
Inductive Model Results

Table 3: Environmental Layer Contributions to Model Fit

<table>
<thead>
<tr>
<th>Layer ID</th>
<th>Percent Contributiona</th>
<th>Layer ID</th>
<th>Percent Contributiona</th>
</tr>
</thead>
<tbody>
<tr>
<td>catsoiltemp</td>
<td>27.7%</td>
<td>contstrmed</td>
<td>3.2%</td>
</tr>
<tr>
<td>contddays</td>
<td>12.2%</td>
<td>contelev</td>
<td>3.1%</td>
</tr>
<tr>
<td>contslope</td>
<td>9.4%</td>
<td>conttmax</td>
<td>2.5%</td>
</tr>
<tr>
<td>contsumrad</td>
<td>6.7%</td>
<td>contnsasp</td>
<td>2.1%</td>
</tr>
<tr>
<td>catesys</td>
<td>6.7%</td>
<td>contmin</td>
<td>1.9%</td>
</tr>
<tr>
<td>contfrsted</td>
<td>4.8%</td>
<td>contewasp</td>
<td>1.5%</td>
</tr>
<tr>
<td>catsoilord</td>
<td>4.7%</td>
<td>contndvi</td>
<td>1.2%</td>
</tr>
<tr>
<td>catgeol</td>
<td>4.1%</td>
<td>contwinrad</td>
<td>0.8%</td>
</tr>
<tr>
<td>contwinpcp</td>
<td>4.1%</td>
<td>contvrm</td>
<td>0.0%</td>
</tr>
<tr>
<td>contprecip</td>
<td>3.4%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a Relative contributions of the layers to the model based on changes in fit (gain) during iterations of the training algorithm.

Table 4: Habitat Suitability Thresholds

<table>
<thead>
<tr>
<th>Measure</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Logistic Thresholda</td>
<td>0.130</td>
</tr>
<tr>
<td>Moderate Logistic Thresholdb</td>
<td>0.382</td>
</tr>
<tr>
<td>Optimal Logistic Thresholdc</td>
<td>NA</td>
</tr>
<tr>
<td>Area of entire modeled range (percent of Montana)</td>
<td>149,695.19 km² (39.3%)</td>
</tr>
<tr>
<td>Total area of predicted suitable habitat within modeled range</td>
<td>127,614.9 km²</td>
</tr>
<tr>
<td>Area of predicted low suitability habitat within modeled range</td>
<td>65,320.4 km²</td>
</tr>
<tr>
<td>Area of moderate suitability habitat within modeled range</td>
<td>62,294.5 km²</td>
</tr>
<tr>
<td>Area of predicted optimal habitat within modeled range</td>
<td>NA</td>
</tr>
</tbody>
</table>

a The logistic threshold between unsuitable and low suitability as determined by Maxent which balances data omission error with minimizing predicted suitable area. This is a conservative threshold that should encompass nearly all potentially suitable habitat for a species.

b The logistic threshold value where the percentage of test observations above the threshold is what would be expected if the observations were randomly distributed across logistic value classes (Hirzel et al. 2006). This is equivalent to a null model. When sample sizes are small, it may be undetermined.

c The logistic threshold where the percentage of test observations above the threshold is 10 times higher than would be expected if the observations were randomly distributed across logistic value classes. When sample sizes are small, it may be undetermined.

Table 5: Evaluation Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low AVIa</td>
<td>98.2%</td>
</tr>
<tr>
<td>Moderate AVIa</td>
<td>73.8%</td>
</tr>
<tr>
<td>Optimal AVIa</td>
<td>NA</td>
</tr>
<tr>
<td>Average Testing Deviance (x ± sd)b</td>
<td>1.604 ± 0.860</td>
</tr>
<tr>
<td>Training AUCc</td>
<td>0.775</td>
</tr>
<tr>
<td>Test AUCd</td>
<td>0.714</td>
</tr>
</tbody>
</table>

a Absolute Validation Index: The proportion of test locations that fall above the low, moderate, or optimal logistic threshold.
b A measure of how well model output matched the location of test observations. In theory, everywhere a test location was located, the logistic value should have been 1.0. The deviance value for each test location is calculated as -2 times the natural log of the associated logistic output value. For example, the equivalent deviance values for the low, moderate and optimal logistic thresholds of this model would be 4.082, 1.923 and NA, respectively. Deviances for individual test locations are plotted in Figure 6.
c The area under a curve obtained by plotting the true positive rate against 1 minus the false positive rate for model training observations (averaged over 10 folds). Values range from 0 to 1 with a random or null model performing at a value of 0.5.
d The same metric described in c, but calculated for test observations.
Figure 1. Jackknife assessment of contribution by individual environmental layers to training gain.

Figure 2. Response curves for the top three contributing environmental layers, mean value in red, +/- one standard deviation in blue. Response curves for additional environmental layers are available upon request.
Inductive Model Map Outputs

Figure 3. Continuous habitat suitability model output (logistic scale).

Figure 4. Standard deviation in the model output across the averaged models.
Figure 5. Continuous habitat suitability model output with the 381 observations used for modeling.

Figure 6. Continuous habitat suitability model output with relative deviance for each observation. Symbol size corresponds to the difference between 1.0 and the optimal, moderate, and low habitat suitability threshold.
Figure 7. Continuous habitat suitability model output with all 1,865 observations (black) and survey locations that could have detected the species (gray).

Figure 8. Model output classified into habitat suitability classes.
Figure 9. Model output classified into habitat suitability classes and aggregated into hexagons at a scale of 259 hectares per hexagon. This is the finest scale suggested for management decisions and survey planning.
**Deductive Modeling**

**Model Limitations and Suggested Uses**

Species associations with ecological systems should be used to generate lists of potential species that may occupy broader landscapes for the purposes of landscape-level planning. Users of this information should be aware that the land cover data used to generate species associations was only intended to be used at broader landscape scales. Land cover mapping accuracy is particularly problematic when the systems occur as small patches or where the land cover types have been altered over the past decade. Thus, particular caution should be used when using the associations in assessments of smaller areas (e.g. less than one quarter of a public land survey system (PLSS) section, <64 hectares). Model outputs should not be used in place of on-the-ground surveys for species, and wildlife and land management agency biologists should be consulted about the value of using these associations to guide habitat management decisions for regional planning efforts or local projects. See Suggested Contacts for State and Federal Natural Resource Agencies attached to this document.

Data used in model evaluation often have locational uncertainties that exceed the 30-meter pixel size of the land cover dataset, potentially intersecting incorrect ecological systems. Additionally, the habitat within a pixel may have been assigned to the wrong ecological system or the habitat may have been modified. As a result, evaluation metrics may be skewed low, especially for species occupying ecotones or patchy ecological systems. Finally, users should note that ecological systems associated with a species are only mapped within the range of that species, although portions of that ecological system may occur elsewhere.

**Deductive Model Methods**

**Modeling Process**

This model is based on the 2016 statewide land cover classifications at 30×30 meter raster pixels ([http://geoinfo.msl.mt.gov/msdi/land_use_land_cover](http://geoinfo.msl.mt.gov/msdi/land_use_land_cover)). Level 3 ecological systems (90) were used for this model and these data were originally mapped at a scale of 1:100,000. In general, species were associated as using an ecological system if structural characteristics of used habitat documented in the literature were present in the ecological system or large numbers of point observations were associated with the ecological system. However, species were not associated with an ecological system if there was no support in the literature for use of structural characteristics in an ecological system, even if point observations were associated with that system. Species were either commonly associated, occasionally associated, or not associated with each ecological system. This assignment was based on the degree to which the structural characteristics of an ecological system matched the preferred structural habitat characteristics for each species in the literature. The percentage of observations associated with each ecological system relative to the percent of Montana covered by each ecological system was also used to guide assignments of habitat quality. Associations are shown in Table 6.

**Model Outputs and Evaluation**

The model output is a spatial dataset of categorical habitat suitability based on ecological system associations (commonly or occasionally associated) within the species’ presumed range (Figure 10) and resulting tabular estimates of the area of commonly and occasionally associated habitat (Table 7). We evaluated this model output based on known or potential distribution and habitat use in Montana and absolute validation indices (AVI) (Hirzel et al. 2006, Ecological Modelling 199:142-152) using presence-only data (Table 8).
## Deductive Model Results

### Table 6: Ecological Systems Associated with Gray Wolf

<table>
<thead>
<tr>
<th>Ecological System</th>
<th>Code</th>
<th>Association</th>
<th>Count*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montane Sagebrush Steppe</td>
<td>5455</td>
<td>Common</td>
<td>48</td>
</tr>
<tr>
<td>Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest</td>
<td>4232</td>
<td>Common</td>
<td>46</td>
</tr>
<tr>
<td>Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland</td>
<td>4242</td>
<td>Common</td>
<td>35</td>
</tr>
<tr>
<td>Rocky Mountain Montane Douglas-fir Forest and Woodland</td>
<td>4266</td>
<td>Common</td>
<td>26</td>
</tr>
<tr>
<td>Rocky Mountain Mesic Montane Mixed Conifer Forest</td>
<td>4234</td>
<td>Common</td>
<td>25</td>
</tr>
<tr>
<td>Rocky Mountain Lodgepole Pine Forest</td>
<td>4237</td>
<td>Common</td>
<td>25</td>
</tr>
<tr>
<td>Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland</td>
<td>4243</td>
<td>Common</td>
<td>19</td>
</tr>
<tr>
<td>Rocky Mountain Lower Montane, Foothill, and Valley Grassland</td>
<td>7112</td>
<td>Common</td>
<td>18</td>
</tr>
<tr>
<td>Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland</td>
<td>9155</td>
<td>Common</td>
<td>17</td>
</tr>
<tr>
<td>Rocky Mountain Subalpine-Montane Mesic Meadow</td>
<td>7118</td>
<td>Common</td>
<td>12</td>
</tr>
<tr>
<td>Rocky Mountain Subalpine-Upper Montane Grassland</td>
<td>7113</td>
<td>Common</td>
<td>8</td>
</tr>
<tr>
<td>Recently burned forest</td>
<td>8501</td>
<td>Common</td>
<td>8</td>
</tr>
<tr>
<td>Post-Fire Recovery</td>
<td>8505</td>
<td>Common</td>
<td>7</td>
</tr>
<tr>
<td>Alpine-Montane Wet Meadow</td>
<td>9217</td>
<td>Common</td>
<td>6</td>
</tr>
<tr>
<td>Insect-Killed Forest</td>
<td>8700</td>
<td>Common</td>
<td>6</td>
</tr>
<tr>
<td>Aspen Forest and Woodland</td>
<td>4104</td>
<td>Common</td>
<td>5</td>
</tr>
<tr>
<td>Harvested forest-tree regeneration</td>
<td>8601</td>
<td>Common</td>
<td>5</td>
</tr>
<tr>
<td>Rocky Mountain Ponderosa Pine Woodland and Savanna</td>
<td>4240</td>
<td>Common</td>
<td>4</td>
</tr>
<tr>
<td>Big Sagebrush Steppe</td>
<td>5454</td>
<td>Common</td>
<td>4</td>
</tr>
<tr>
<td>Harvested forest-grass regeneration</td>
<td>8603</td>
<td>Common</td>
<td>3</td>
</tr>
<tr>
<td>Rocky Mountain Lower Montane-Foothill Riparian Woodland and Shrubland</td>
<td>9156</td>
<td>Common</td>
<td>3</td>
</tr>
<tr>
<td>Rocky Mountain Subalpine Woodland and Parkland</td>
<td>4233</td>
<td>Common</td>
<td>2</td>
</tr>
<tr>
<td>Rocky Mountain Montane-Foothill Deciduous Shrubland</td>
<td>5312</td>
<td>Common</td>
<td>2</td>
</tr>
<tr>
<td>Rocky Mountain Subalpine Deciduous Shrubland</td>
<td>5326</td>
<td>Common</td>
<td>2</td>
</tr>
<tr>
<td>Burned Sagebrush</td>
<td>8504</td>
<td>Common</td>
<td>1</td>
</tr>
<tr>
<td>Harvested forest-shrub regeneration</td>
<td>8602</td>
<td>Common</td>
<td>1</td>
</tr>
<tr>
<td>Emergent Marsh</td>
<td>9222</td>
<td>Common</td>
<td>1</td>
</tr>
<tr>
<td>Active and Stabilized Dune</td>
<td>3160</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Rocky Mountain Foothill Limber Pine - Juniper Woodland</td>
<td>4236</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Rocky Mountain Poor Site Lodgepole Pine Forest</td>
<td>4267</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Great Plains Ponderosa Pine Woodland and Savanna</td>
<td>4280</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Aspen and Mixed Conifer Forest</td>
<td>4302</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Mountain Mahogany Woodland and Shrubland</td>
<td>4303</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Great Plains Wooded Draw and Ravine</td>
<td>4328</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Mat Saltbush Shrubland</td>
<td>5203</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Low Sagebrush Shrubland</td>
<td>5209</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Big Sagebrush Shrubland</td>
<td>5257</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Mixed Salt Desert Scrub</td>
<td>5258</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Great Plains Shrubland</td>
<td>5262</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Rocky Mountain Lower Montane-Foothill Shrubland</td>
<td>5263</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Rocky Mountain Foothill Woodland-Steppe Transition</td>
<td>5426</td>
<td>Common</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 6: Ecological Systems Associated with Gray Wolf

<table>
<thead>
<tr>
<th>Ecological System</th>
<th>Code</th>
<th>Association</th>
<th>Counta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great Plains Mixedgrass Prairie</td>
<td>7114</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Great Plains Sand Prairie</td>
<td>7121</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Introduced Upland Vegetation - Shrub</td>
<td>8402</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Introduced Upland Vegetation - Annual and Biennial Forbland</td>
<td>8403</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Introduced Upland Vegetation - Annual Grassland</td>
<td>8404</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Introduced Upland Vegetation - Perennial Grassland and Forbland</td>
<td>8405</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Recently burned grassland</td>
<td>8502</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Recently burned shrubland</td>
<td>8503</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Greasewood Flat</td>
<td>9103</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Rocky Mountain Conifer Swamp</td>
<td>9111</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Great Plains Floodplain</td>
<td>9159</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Rocky Mountain Wooded Vernal Pool</td>
<td>9162</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Rocky Mountain Subalpine-Montane Riparian Woodland</td>
<td>9171</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Rocky Mountain Subalpine-Montane Riparian Shrubland</td>
<td>9187</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Great Plains Prairie Pothole</td>
<td>9203</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Great Plains Open Freshwater Depression Wetland</td>
<td>9218</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Rocky Mountain Subalpine-Montane Fen</td>
<td>9234</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Great Plains Closed Depressional Wetland</td>
<td>9252</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Great Plains Saline Depression Wetland</td>
<td>9256</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Great Plains Riparian</td>
<td>9326</td>
<td>Common</td>
<td>0</td>
</tr>
<tr>
<td>Alpine Turf</td>
<td>7117</td>
<td>Occasional</td>
<td>2</td>
</tr>
<tr>
<td>Alpine Bedrock and Scree</td>
<td>3135</td>
<td>Occasional</td>
<td>0</td>
</tr>
<tr>
<td>Alpine Dwarf-Shrubland</td>
<td>5207</td>
<td>Occasional</td>
<td>0</td>
</tr>
<tr>
<td>Alpine Fell-Field</td>
<td>7116</td>
<td>Occasional</td>
<td>0</td>
</tr>
</tbody>
</table>

a A count of the observation records intersecting each ecological system, based on the 381 observation records used in the inductive model (see Table 1). This may be zero if the number of observations is low or if the ecological system is patchy.

Table 7: Area of Range and Ecological System (ES) Classes

<table>
<thead>
<tr>
<th>Measure</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of entire modeled range (percent of Montana)</td>
<td>149,695.19 km² (39.3%)</td>
</tr>
<tr>
<td>Area of Commonly and Occasionally Associated ES</td>
<td>136,714.0 km²</td>
</tr>
<tr>
<td>Area of Commonly Associated ES</td>
<td>133,322.0 km²</td>
</tr>
<tr>
<td>Area of Occasionally Associated ES</td>
<td>3,392.0 km²</td>
</tr>
</tbody>
</table>

Table 8: Evaluation Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commonly and Occasionally Associated ES AVIa</td>
<td>89.5%</td>
</tr>
<tr>
<td>Commonly Associated ES AVIa</td>
<td>89.0%</td>
</tr>
<tr>
<td>Occasionally Associated ES AVIa</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

a Absolute Validation Index: The proportion of test locations that fall within the class(es).
Deductive Model Map Output

Figure 10. Deductive model output classified into habitat associations.
Suggested Contacts for State and Federal Natural Resource Agencies

As required by Montana statute (MCA 90-15), the Montana Natural Heritage Program works with state, federal, tribal, nongovernmental organizations, and private partners to ensure that the latest animal and plant distribution and status information is incorporated into our databases so that it can be used to inform a variety of planning processes and management decisions. In addition to the information you receive from us, we encourage you to contact state, federal, and tribal resource management agencies in the area where your project is located. They may have additional data or management guidelines relevant to your efforts. In particular, we encourage you to contact the Montana Department of Fish, Wildlife, and Parks for the latest data and management information regarding hunted and high profile management species and to use the U.S. Fish and Wildlife Service’s Information Planning and Conservation (IPAC) website http://ecos.fws.gov/ipac/ regarding U.S. Endangered Species Act listed Threatened, Endangered, or Candidate species.

For your convenience, we have compiled a list of relevant agency contacts and links below:

**Montana Fish, Wildlife, and Parks**

<table>
<thead>
<tr>
<th>Fish Species</th>
<th>Contact Name</th>
<th>Contact Email</th>
<th>Phone Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish Species</td>
<td>Zachary Shattuck</td>
<td><a href="mailto:zshattuck@mt.gov">zshattuck@mt.gov</a></td>
<td>(406) 444-1231</td>
</tr>
<tr>
<td>Fish Species</td>
<td>Lee Nelson</td>
<td><a href="mailto:leenelson@mt.gov">leenelson@mt.gov</a></td>
<td>(406) 444-2447</td>
</tr>
<tr>
<td>American Bison</td>
<td>Lauri Hanauska-Brown</td>
<td><a href="mailto:LHanauska-Brown@mt.gov">LHanauska-Brown@mt.gov</a></td>
<td>(406) 444-5209</td>
</tr>
<tr>
<td>Black-footed Ferret</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black-tailed Prairie Dog</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bald Eagle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Golden Eagle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common Loon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Least Tern</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piping Plover</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whooping Crane</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Regional Contacts**

- Region 1 (Kalispell) (406) 752-5501
- Region 2 (Missoula) (406) 542-5500
- Region 3 (Bozeman) (406) 994-4042
- Region 4 (Great Falls) (406) 454-5840
- Region 5 (Billings) (406) 247-2940
- Region 6 (Glasgow) (406) 228-3700
- Region 7 (Miles City) (406) 234-0900

**Gray Wolf (Canis lupus) Predicted Suitable Habitat Modeling**

**U.S. Fish and Wildlife Service**
Information Planning and Conservation (IPAC) website: [http://ecos.fws.gov/ipac/](http://ecos.fws.gov/ipac/)

**Bureau of Land Management**
Montana Field Office Contacts:

<table>
<thead>
<tr>
<th>Location</th>
<th>Phone Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Billings</td>
<td>(406) 896-5013</td>
</tr>
<tr>
<td>Butte</td>
<td>(406) 533-7600</td>
</tr>
<tr>
<td>Dillon</td>
<td>(406) 683-8000</td>
</tr>
<tr>
<td>Glasgow</td>
<td>(406) 228-3750</td>
</tr>
<tr>
<td>Havre</td>
<td>(406) 262-2820</td>
</tr>
<tr>
<td>Lewistown</td>
<td>(406) 538-1900</td>
</tr>
<tr>
<td>Malta</td>
<td>(406) 654-5100</td>
</tr>
<tr>
<td>Miles City</td>
<td>(406) 233-2800</td>
</tr>
<tr>
<td>Missoula</td>
<td>(406) 329-3914</td>
</tr>
</tbody>
</table>

**United States Forest Service**

<table>
<thead>
<tr>
<th>Program Leader/Ecologist</th>
<th>Email Address</th>
<th>Phone Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wildlife Program Leader:</td>
<td>Tammy Fletcher <a href="mailto:tammyfletcher@fs.fed.us">tammyfletcher@fs.fed.us</a></td>
<td>(406) 329-3588</td>
</tr>
<tr>
<td>Wildlife Ecologist:</td>
<td>Cara Staab <a href="mailto:cstaab@fs.fed.us">cstaab@fs.fed.us</a></td>
<td>(406) 329-3677</td>
</tr>
<tr>
<td>Fish Program Leader:</td>
<td>Scott Spaulding <a href="mailto:scottspaulding@fs.fed.us">scottspaulding@fs.fed.us</a></td>
<td>(406) 329-3287</td>
</tr>
<tr>
<td>Fish Ecologist:</td>
<td>Cameron Thomas <a href="mailto:cathomas@fs.fed.us">cathomas@fs.fed.us</a></td>
<td>(406) 329-3087</td>
</tr>
<tr>
<td>TES Program:</td>
<td>Lydia Allen <a href="mailto:lallen@fs.fed.us">lallen@fs.fed.us</a></td>
<td>(406) 329-3558</td>
</tr>
<tr>
<td>Interagency Grizzly Bear Coordinator:</td>
<td>Scott Jackson <a href="mailto:sjackson03@fs.fed.us">sjackson03@fs.fed.us</a></td>
<td>(406) 329-3664</td>
</tr>
<tr>
<td>Regional Botanist:</td>
<td>Steve Shelly <a href="mailto:sshelly@fs.fed.us">sshelly@fs.fed.us</a></td>
<td>(406) 329-3041</td>
</tr>
</tbody>
</table>

**Regional Office – Missoula, Montana Contacts**

Model report version 2.0 – revised 20 October 2017