APPENDIX 2 – ENVIRONMENTAL DATA

CLIMATE

Climate variables were generated by applying the BIOCLIM algorithms (Nix 1986) to DAYMET climate data (Thornton et al. 1997, Thornton and Running 1999, Thornton et al. 2000). This was done by running ARC/INFO AMLs, written by Robert Hijmans (available at http://worldclim.org) and modified by WYNDD, on 18-year DAYMET averages downloaded from http://www.daymet.org/climateSummary.jsp on 11/2/2005. The resulting rasters were converted to integer grids by multiplying each grid by a scaling factor (see Table A4.1), to produce grids that maintained the desired precision while reducing the file size of each raster. This was originally done to reduce the file size required for these variables. The native resolution of DAYMET data is 1 km, so we resampled the resulting BIOCLIM layers to 30 m, using the Bilinear Interpolation option in the Resample tool in ArcToolbox to produce raster layers matching the cell size, alignment, extent, and projection of the other environmental layers. The resulting bioclimatic predictor layers are given in the table below. All climate variables were included in the base set of predictors tested for all species, however, "t9" was later excluded from any subsequent models, as it produced spurious artifacts in the resulting model output for some species.

TABLE A4.1. CLIMATE PREDICTORS

Climate Variable	*Name*	*Scale Factor*	*Resulting Units*	*Number of Final Models Using Variable*
Annual mean precipitation	"p1"	10	0. 1 cm	4
Precipitation of the wettest month	"p2"	10	0. 1 cm	9
Precipitation of the driest month	"p3"	10	0. 1 cm	6
Annual precipitation range (p3 – p2)	"p4"	10	0. 1 cm	14
Precipitation of the wettest quarter	"p5"	10	0. 1 cm	4
Precipitation of the driest quarter	"p6"	10	0. 1 cm	8
Precipitation of the warmest quarter	"p7"	10	0. 1 cm	19
Precipitation of the coldest quarter	"p8"	10	0. 1 cm	13
Variation of monthly precipitation	"p9"	10	0. 1 cm	36
Annual mean relative humidity	"h1"	100	0.01%	9
Relative Humidity of the most humid month	"h2"	100	0.01%	15
Relative Humidity of the least humid month	"h3"	100	0.01%	9
Annual RH range	"h4"	100	0.01%	13
Variation of monthly RH	"h5"	100	0.01%	12

Climate Variable	*Name*	*Scale Factor*	*Resulting Units*	*Number of Final Models Using Variable*
Annual total radiation	"r1"	100	0.01 MJ/m²/day	11
Radiation of the lightest month	"r2"	100	0.01 MJ/m²/day	27
Radiation of the darkest month	"r3"	100	0.01 MJ/m²/day	13
Annual radiation range	"r4"	100	0.01 MJ/m²/day	9
Variation of monthly radiation	"r5"	100	0.01 MJ/m²/day	26
Annual mean temperature	"t1"	10	0.1 °C	9
Mean diurnal temperature range	"t2"	10	0.1 °C	7
Hottest month mean maximum temperature	"t3"	10	0.1 °C	18
Coldest month mean minimum temperature	"t4"	10	0.1 °C	24
Annual temperature range (T3 – T4)	"t5"	10	0.1 °C	11
Isothermality (T2/T5)	"t6"	10	0.1 °C	11
Standard deviation of monthly temperature	"t7"	10	0.1 °C	9
Wettest quarter mean temperature	"t8"	10	0.1 °C	36
Driest quarter mean temperature	"t9"	10	0.1 °C	7
Warmest quarter mean temperature	"t10"	10	0.1 °C	19
Coldest quarter mean temperature	"t11"	10	0.1 °C	11
Annual number of frost days	"tf_a"	10	0.1 Days	15
Interannual variation in annual number of frost days	"tf_s"	10	0.1 Days	23

HYDROLOGY

Distance to Water Layers

We generated our initial set of 6 hydrology layers (Table A4.2) by calculating straight line distances, in meters, to selected water features mapped in the National Hydrography Dataset (Simley and Carswell 2009). We calculated these distances in two ways. First, we calculated the distance to water, using mapped polygons to represent lakes and large rivers. This produced rasters with values of 0 m both along the shores and in open water areas of lakes and large rivers. This is appropriate for species such as waterfowl that may make use of open water as frequently as they make use of areas nearer to shore; however, it is likely not a good way to understand use by species that occur in the littoral zone or on the shores of water bodies, such as wading birds or amphibians.

Thus, we also generated a second set of distance to water layers -- "d2ws," "d2pws," and "d2psws" -- by first converting the polygon representations of lakes and major rivers to linear features. When distance values were calculated with this set, only shorelines received a value of 0 m. Areas further from shorelines (either toward the center of the water body or landward) received increasingly larger values.

After running preliminary, variable-reduction models, we noted two problems with the NHD data as we originally incorporated it. The first problem, which affected both the "d2w" and "d2pw" layers, was that some major streams (e.g. Green River, the North Platte River) were mapped only as polygons and were only present in a feature class within the NHD that we did not originally incorporate into our distance calculations. The second problem, which only impacted the "d2pw" layer, was that in limited portions of the state, many small ephemeral and intermittent streams were incorrectly attributed as perennial streams. We corrected the first problem by integrating major streams mapped as polygons, and the second problem by manually removing streams that were clearly ephemeral or intermittent from the permanent water features dataset. We then recalculated the distance layers to incorporate these revisions, resulting in the revised layers "d2w2" and "d2pw2." Note that for several species, the NHD data problems did not significantly impact the quality of the model (typically because the problematic areas were outside the species' ranges), so the original variables -- "d2w" and "d2pw" -- were not replaced in the final models by the revised layers.

Finally, based on preliminary modeling, we also generated a "distance to permanent, flowing water" variable ("d2pfw") to use in modeling species that may be more associated with permanent flowing water than with permanent standing water. All of the distance to water variables were included in the base set of potential predictors (using the original layers initially, and the revised set during re-runs for selected species). Some of these predictors were used in many species' final models; others were not used in any final models.

TABLE A4.2. HYDROLOGY PREDICTORS

Variable	*Name*	*Note*	*Number of Final Models Using Variable*
Distance to Water	"d2w"	Straight line distance to any surface water feature in the NHD dataset.	3
Distance to Permanent Water	"d2pw"	Straight line distance to any permanent surface water feature.	5
Distance to Permanent Standing Water	"d2psw"	Straight line distance to any permanent standing. surface water feature	2
Distance to Water Shorelines	"d2ws"	As with "d2w," but calculating distance to the shorelines of lakes and large rivers, rather than to the water surface, such that shorelines have a value of 0 m, but values get larger toward the center of the lake or major river.	1
Distance to Permanent Water Shoreline	"d2pws"	As with "d2pw," but calculating distance to shorelines.	0

Variable	*Name*	*Note*	*Number of Final Models Using Variable*
Distance to Permanent Standing Water Shorelines	"d2psws"	As with "d2psw," but calculating distance to shorelines.	0
Distance to Water (Revised)	"d2w2"	As with "d2w," but with revisions to the selected NHD features to correct missing or incorrect features.	3
Distance to Permanent Water (Revised)	"d2pw2"	As with "d2pw," but with revisions to the selected NHD features to correct missing or incorrect features.	36
Distance to Permanent Flowing Water	"d2pfw"	Straight line distance to any permanent, flowing surface water feature.	1

"Neighborhood" Water Layers

The "distance to water" variables were problematic with some species, as many observations for species like waterbirds are actually recorded at locations some distance from the water, where the observer was standing. This led to spurious models that predicted these species as occurring in narrow bands around, but some distance from, the water features they actually use. Additionally, many species associated with permanent water features were predicted to occur in drier parts of the state where appropriate habitat (i.e., permanent water bodies) likely is too sparse for these species to occur.

To resolve these issues, we generated a series of "neighborhood" water layers that quantified the prevalence of selected features from the NHD in a given neighborhood around each pixel (Table A4.3). We did this by generating a series of features representing our target water features and assigning these features a value of "1" in a binary raster layer (all other values were set to "0"), and then calculating a Focal Mean statistic for 3 different neighborhood sizes using ArcToolbox. This resulted in indices with values ranging from "0" (none of the cells in the neighborhood surrounding a cell contain the selected water features) to "1" (all cells surrounding the focal cell contain the selected water features). These "neighborhood water" layers were tested for species where the "distance to water" layers produced spurious artifacts.

Table A4.3. Neighborhood Water Predictors

Variable	*Name*	*Selected NHD Features*	*Number of Final Models Using Variable*
Prevalence of Lakes/Large Rivers within 300 m	"bw300"	Permanent lakes, ponds, and reservoirs and large streams mapped as polygon features	2
Prevalence of Lakes/Large Rivers within 1600 m	"bw1600"	Permanent lakes, ponds, and reservoirs and large streams mapped as polygon features	5
Prevalence of Lakes/Large Rivers within 3200 m	"bw3200"	Permanent lakes, ponds, and reservoirs and large streams mapped as polygon features	2
Prevalence of Flowing Water within 300 m	"fw300"	Permanent streams mapped as linear and polygon features	1
Prevalence of Flowing Water within 1600 m	"fw1600"	Permanent streams mapped as linear and polygon features	0
Prevalence of Flowing Water within 3200 m	"fw3200"	Permanent streams mapped as linear and polygon features	2
Prevalence of Permanent Standing Water within 300 m	"ps300"	Lakes, ponds, and reservoirs *not* described as intermittent or ephemeral	0
Prevalence of Permanent Standing Water within 1600 m	"ps1600"	Lakes, ponds, and reservoirs *not* described as intermittent or ephemeral	3
Prevalence of Permanent Standing Water within 3200 m	"ps3200"	Lakes, ponds, and reservoirs *not* described as intermittent or ephemeral	0

LAND COVER

Most land cover variables in which we were interested (e.g., percent conifer forest cover, percent deciduous) were not readily available in any one dataset, requiring the production of synthetic index variables that typically incorporated values from LANDFIRE data (Comer et al. 2003), GAP Land Cover (Gap Analysis Program 2010), and/or the USGS Sagebrush dataset (Homer et al. 2009). Thus, for most of the land cover index variables we used (Table A4.4), the variables were a blending of various datasets.

Table A4.4. Synthetic Land Cover Predictors

Variable	*Name*	*Number of Final Models Using Variable*
Conifer Index	"confr"	46
Ponderosa Pine Index	"pipoc"	1
Deciduous Forest Index	"decid"	29
Cottonwood Index	"pode"	19
Shrub Cover Index	"shrub"	9
Sagebrush Index	"sage"	25
Herbaceous Cover Index	"herb"	33

We created these synthetic indices by first assigning each GAP ecological system a score relative to the desired predictors (Table A4.5). Note that the GAP scores used to create the Pinyon-Juniper ("pj") and herbaceous cover ("herb") indices are also given in Table A4.5 below. However, "pj" did not integrate a LANDFIRE canopy cover value into its scoring, and "herb" integrated it differently than did the other indices (see the process description outlined for these variables under the appropriate headings below).

Table A4.5. Scoring for Synthetic Variables by GAP Ecological System

Ecological System	*GAP "confr" Score*	*GAP "pj" Score*	*GAP "pipo" Score*	*GAP "decid" Score*	*GAP "pode" Score*	*GAP "Shrub" Score*	*GAP "herb" Score*	*GAP "Sage" Score*
Columbia Plateau Low Sagebrush Steppe	1	0.01	0	0	0	0.75	0.25	0.75
Columbia Plateau Steppe and Grassland	1	0.01	0	0	0	0.5	0.50	0.25
Columbia Plateau Vernal Pool	0	0	0	0	0	0	0.75	0
Cultivated Cropland	0	0	0	0	0	0.05	0.25	0
Developed, High Intensity	0	0	0	0	0	0.05	0.05	0
Developed, Low Intensity	0.5	0	0	0.5	0.25	0.05	0.05	0
Developed, Medium Intensity	0.5	0	0	0.5	0.25	0.05	0.05	0
Developed, Open Space	0.5	0	0.05	0.5	0.25	0.25	0.50	0.25

ECOLOGICAL SYSTEM	GAP "CONFR" SCORE	GAP "PJ" SCORE	GAP "PIPO" SCORE	GAP "DECID" SCORE	GAP "PODE" SCORE	GAP "SHRUB" SCORE	GAP "HERB" SCORE	GAP "SAGE" SCORE
Geysers and Hot Springs	0	0	0	0	0	0	0.00	0
Great Basin Foothill and Lower Montane Riparian Woodland and Shrubland	0.25	0	0	0.75	0.75	0.05	0.05	0
Great Basin Xeric Mixed Sagebrush Shrubland	0	0	0	0	0	0.5	0.05	0.75
Great Plains Prairie Pothole	0	0	0	0	0	0	0.75	0
Harvested forest-grass regeneration	0.95	0	0	0.05	0	0.05	0.95	0
Harvested forest-shrub regeneration	0.95	0	0	0.05	0	0.75	0.25	0
Harvested forest-tree regeneration	0.95	0	0	0.05	0	0.05	0.25	0
Inter-Mountain Basins Active and Stabilized Dune	0	0	0	0	0	0.25	0.05	0.5
Inter-Mountain Basins Alkaline Closed Depression	0	0	0	0	0	0.25	0.05	0.5
Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland	0.5	0	0.05	0.5	0	0.25	0.05	0
Inter-Mountain Basins Big Sagebrush Shrubland	1	0.01	0	0	0	0.75	0.05	0.95
Inter-Mountain Basins Big Sagebrush Steppe	0	0	0	0	0	0.95	0.05	0.75
Inter-Mountain Basins Cliff and Canyon	1	0.1	0	0	0	0.05	0.00	0.5
Inter-Mountain Basins Greasewood Flat	0	0	0	0	0	0.75	0.25	0.25

ECOLOGICAL SYSTEM	GAP "CONFR" SCORE	GAP "PJ" SCORE	GAP "PIPO" SCORE	GAP "DECID" SCORE	GAP "PODE" SCORE	GAP "SHRUB" SCORE	GAP "HERB" SCORE	GAP "SAGE" SCORE
Inter-Mountain Basins Interdunal Swale Wetland	0	0	0	0	0	0	1.00	0
Inter-Mountain Basins Juniper Savanna	1	1	0	0	0	0.5	0.25	0.25
Inter-Mountain Basins Mat Saltbush Shrubland	0	0	0	0	0	0.95	0.05	0.25
Inter-Mountain Basins Mixed Salt Desert Scrub	0	0	0	0	0	0.5	0.25	0.5
Inter-Mountain Basins Montane Sagebrush Steppe	0	0	0	0	0	0.75	0.25	0.95
Inter-Mountain Basins Mountain Mahogany Woodland and Shrubland	1	0.01	0.05	0	0	0.75	0.05	0.25
Inter-Mountain Basins Playa	0	0	0	0	0	0.25	0.05	0.75
Inter-Mountain Basins Semi-Desert Grassland	0	0	0	0	0	0.25	0.75	0.75
Inter-Mountain Basins Semi-Desert Shrub-Steppe	0	0	0	0	0	0.5	0.50	0.5
Inter-Mountain Basins Shale Badland	0	0	0	0	0	0.05	0.05	0.25
Introduced Riparian and Wetland Vegetation	0.05	0	0	0.05	0	0.25	0.25	0
Introduced Upland Vegetation - Annual Grassland	0	0	0	0	0	0.05	0.95	0
Introduced Upland Vegetation - Forbland	0	0	0	0	0	0.05	0.95	0

Ecological System	GAP "CONFR" Score	GAP "PJ" Score	GAP "PIPO" Score	GAP "DECID" Score	GAP "PODE" Score	GAP "Shrub" Score	GAP "HERB" Score	GAP "Sage" Score
Introduced Upland Vegetation - Perennial Grassland	0	0	0	0	0	0.05	0.95	0
Introduced Upland Vegetation - Shrub	0	0	0	0	0	0.75	0.25	0
Introduced Upland Vegetation - Treed	0.25	0	0	0.25	0	0.05	0.05	0
Middle Rocky Mountain Montane Douglas-fir Forest and Woodland	1	0	0	0	0	0.25	0.25	0.05
North American Alpine Ice Field	0	0	0	0	0	0	0.00	0
North American Arid West Emergent Marsh	0	0	0	0	0	0	0.25	0
Northern Rocky Mountain Conifer Swamp	1	0	0	0	0	0	0.50	0
Northern Rocky Mountain Foothill Conifer Wooded Steppe	1	0	0.5	0	0	0.25	0.05	0.5
Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland	0.25	0	0	0.75	0.75	0.05	0.05	0
Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland	0	0	0	0	0	0.05	0.95	0.25
Northern Rocky Mountain Mesic Montane Mixed Conifer Forest	0.75	0	0.25	0.25	0	0.25	0.25	0

Ecological System	GAP "CONFR" Score	GAP "PJ" Score	GAP "PIPO" Score	GAP "DECID" Score	GAP "PODE" Score	GAP "SHRUB" Score	GAP "HERB" Score	GAP "SAGE" Score
Northern Rocky Mountain Montane-Foothill Deciduous Shrubland	0.05	0	0	0	0	0.75	0.25	0.05
Northern Rocky Mountain Ponderosa Pine Woodland and Savanna	1	0	1	0	0	0.25	0.05	0.25
Northern Rocky Mountain Subalpine Deciduous Shrubland	0	0	0	0	0	0.95	0.05	0
Northern Rocky Mountain Subalpine Woodland and Parkland	1	0	0	0		0.05	0.25	0
Northern Rocky Mountain Subalpine-Upper Montane Grassland	0	0	0	0	0	0	1.00	0
Northwestern Great Plains - Black Hills Ponderosa Pine Woodland and Savanna	0.5	0.01	0.5	0.5	0	0.05	0.25	0
Northwestern Great Plains Mixedgrass Prairie	1	0	0	0	0	0.05	0.95	0
Northwestern Great Plains Riparian	0	0	0	1	1	0.25	0.25	0.05
Northwestern Great Plains Shrubland	1	0.25	0	0	0	0.75	0.25	0
Open Water	0	0	0	0	0	0	0.00	0
Pasture/Hay	0.5	0	0	0.5	0.05	0.25	0.75	0.05

Ecological System	GAP "CONFR" Score	GAP "PJ" Score	GAP "PIPO" Score	GAP "DECID" Score	GAP "PODE" Score	GAP "SHRUB" Score	GAP "HERB" Score	GAP "SAGE" Score
Quarries, Strip Mines and Gravel Pits	0	0	0	0	0	0	0.00	0
Recently burned forest	0.75	0	0	0.25	0	0.05	0.05	0
Recently burned grassland	0	0	0	0	0	0.05	0.25	0.05
Rocky Mountain Alpine Bedrock and Scree	0	0	0	0	0	0	0.25	0
Rocky Mountain Alpine Dwarf-Shrubland	0	0	0	0	0	0.5	0.50	0
Rocky Mountain Alpine Fell-Field	0	0	0	0	0	0	0.25	0
Rocky Mountain Alpine Turf	0	0	0	0	0	0.25	0.75	0.05
Rocky Mountain Alpine-Montane Wet Meadow	0	0	0	0	0	0	1.00	0
Rocky Mountain Aspen Forest and Woodland	0.25	0	0	0.75	0	0.05	0.25	0
Rocky Mountain Bigtooth Maple Ravine	0.25	0	0	0.75	0	0.25	0.25	0.05
Rocky Mountain Cliff, Canyon and Massive Bedrock	1	0.05	0.25	0	0	0.05	0.00	0
Rocky Mountain Foothill Limber Pine-Juniper Woodland	1	1	0	0	0	0.05	0.05	0.25
Rocky Mountain Lodgepole Pine Forest	0.95	0	0	0.05	0	0.05	0.05	0
Rocky Mountain Lower Montane Riparian Woodland and Shrubland	0.25	0	0	0.75	0.75	0.05	0.05	0
Rocky Mountain Lower Montane-Foothill Shrubland	0.05	0	0	0.05	0	0.75	0.25	0

Ecological System	GAP "CONFR" Score	GAP "PJ" Score	GAP "PIPO" Score	GAP "DECID" Score	GAP "PODE" Score	GAP "SHRUB" Score	GAP "HERB" Score	GAP "SAGE" Score
Rocky Mountain Poor Site Lodgepole Pine Forest	0.95	0	0.05	0	0	0.05	0.05	0.25
Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	0.95	0	0	0.05	0	0.05	0.05	0.25
Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland	1	0	0	0	0	0.05	0.05	0
Rocky Mountain Subalpine-Montane Fen	0	0	0	0	0	0	0.95	0
Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland	1	0	0.05	0	0	0.05	0.05	0
Rocky Mountain Subalpine-Montane Mesic Meadow	0	0	0	0	0	0	1.00	0
Rocky Mountain Subalpine-Montane Riparian Shrubland	0	0	0	0	0	0.95	0.00	0
Rocky Mountain Subalpine-Montane Riparian Woodland	0.75	0.1	0	0.25	0.05	0.05	0.00	0
Ruderal Upland - Old Field	0.5	0	0	0.5	0.05	0.25	0.50	0.05
Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland	1	0	0.5	0	0	0.25	0.05	0

Ecological System	GAP "CONFR" Score	GAP "PJ" Score	GAP "PIPO" Score	GAP "DECID" Score	GAP "PODE" Score	GAP "SHRUB" Score	GAP "HERB" Score	GAP "SAGE" Score
Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland	0.75	0	0.25	0.25	0	0.25	0.25	0
Southern Rocky Mountain Montane-Subalpine Grassland	0.75	0	0	0.25	0	0	0.75	0
Southern Rocky Mountain Ponderosa Pine Woodland	0.95	0.05	0.75	0.05	0	0.25	0.05	0.25
Western Great Plain Saline Depression Wetland	0	0	0	0	0	0	1.00	0
Western Great Plains Badland	0	0	0	0	0	0.05	0.05	0.25
Western Great Plains Cliff and Outcrop	0	0	0	0	0	0.05	0.05	0.05
Western Great Plains Closed Depression Wetland	0	0	0	0	0	0	0.95	0
Western Great Plains Dry Bur Oak Forest and Woodland	0.5	0	0	0.5	0	0.25	0.50	0
Western Great Plains Floodplain	0	0	0	1	0.25	0.25	0.25	0.05
Western Great Plains Foothill and Piedmont Grassland	0	0	0	0	0	0	1.00	0
Western Great Plains Open Freshwater Depression Wetland	0	0	0	0	0	0	0.75	0

Ecological System	*GAP "CONFR" Score*	*GAP "PJ" Score*	*GAP "PIPO" Score*	*GAP "DECID" Score*	*GAP "PODE" Score*	*GAP "Shrub" Score*	*GAP "HERB" Score*	*GAP "Sage" Score*
Western Great Plains Riparian Woodland and Shrubland	0.05	0	0	0.95	0.95	0.25	0.25	0.05
Western Great Plains Sand Prairie	0	0	0	0	0	0.05	0.75	0
Western Great Plains Shortgrass Prairie	0	0	0	0	0	0.05	0.95	0.25
Western Great Plains Wooded Draw and Ravine	0.25	0.05	0	0.75	0	0.25	0.25	0
Wyoming Basins Dwarf Sagebrush Shrubland and Steppe	0	0	0	0	0	0.75	0.25	0.95

The ecological systems score for each pixel in the study area then was mathematically combined with the LANDFIRE estimate of the appropriate canopy cover (i.e., forest or shrub cover) for that pixel to come up with an index for each category. For forested systems, we combined the ecological system score with LANDFIRE forest canopy cover data using the following formula:

$$\text{Index} = \text{GAP Ecological System Score} * (\text{LANDFIRE Forest Canopy Cover})^{\wedge\, 0.75}$$

GAP ecological systems scores refer to the prevalence of the forest type *among tree species*. For example, if a system is 50% grass and 50% trees, but all the trees are coniferous, the conifer score would be 1.00, because all trees in the system are conifers (Table A4.6).

Notice that the exponential power weighted the LANDFIRE data slightly higher than the ecological systems data, because LANDFIRE was specifically designed to accurately predict tree canopy cover. Thus, for *a given pixel* we had more faith that LANDFIRE data represents actual tree cover present. Scores were all between 0 and 1, so raising them to a fractional power increases their value slightly, such that 0.1 became 0.18, 0.6 became 0.68, 0.9 became 0.92. Low values were increased proportionally more than high values, but we believe that this did not substantially alter the final index. Using ponderosa pine as an example, this yields an index for each pixel ranging from zero to one, as follows:

> 1.0 -- Pixel has 100% canopy cover of an ecological system that is almost entirely ponderosa pine (i.e., if there are trees in the pixel, they are almost certainly ponderosa pine).

0.5 -- Pixel is less likely to be ponderosa-dominated than higher index values. It could have high canopy cover of a system that has a large non-ponderosa component, or it could have low canopy cover of a system that is largely dominated by ponderosa.

Close to 0 -- Pixel has very low canopy cover and/or is a system that has a very small ponderosa component.

TABLE A4.6. GAP ECOLOGICAL SYSTEM SCORE DEFINITIONS FOR TREE INDICES

Score	*Tree Groups: Conifer ("confr"), Deciduous ("decid") -- Conifer used in the examples below)*	*Specific Taxa of Trees:* *Ponderosa ("pipo"), Pinyon-Juniper ("pj"), or Cottonwood ("pode") -- ponderosa used in the examples below)*
1.00	Dominant tree species are almost entirely coniferous trees.	The dominant tree species is almost entirely ponderosa pine.
0.95	Dominant tree species are largely conifers, but the description notes occasional co-dominants or scattered occurrences of other species.	The dominant tree species is largely ponderosa pine, but the description notes occasional co-dominants or scattered occurrences of other species.
0.75	Dominant tree species are mostly conifer, but there can be a *substantial* portion of deciduous trees that co-dominate, such as aspen or cottonwood. For example: "Douglas fir and lodgepole pine trees typically dominate, although in some areas aspen can dominate the canopy. "	The dominant tree species is mostly ponderosa pine, but there can be a *substantial* portion of other trees (including deciduous trees) that co-dominate. For example: "Ponderosa pine typically dominates the canopy, although lodgepole pine trees can co-dominate and in some areas aspen can dominate the canopy. "
0.50	At least half the trees are <u>not</u> conifers. For example: "Aspen is the key indicator species, but several other tree species are generally mixed in the canopy, including pines and firs." or "System consists of deciduous, coniferous, and mixed conifer-deciduous forests that occur on streambanks and river floodplains."	At least half the trees are not ponderosa pine. For example: "Limber pine is the key indicator species, but several other tree species are generally mixed in the canopy, including ponderosa pine."
0.25	Most of the trees are <u>not</u> conifers, but a *substantial* portion of conifer trees co-dominate. For example: "Aspen trees typically dominate this system, although in some areas junipers can dominate the canopy."	Most of the trees are <u>not</u> ponderosa pine, but a *substantial* portion of ponderosa trees co-dominate. For example: "Junipers typically dominate this system, although in some areas ponderosa pine can dominate the canopy."
0.05	Conifers occur occasionally, or in small pockets. For example: "Scattered junipers or pines may also occur. "	Ponderosa pine occurs occasionally, or in small pockets. For example: "Scattered ponderosa pines may also occur. "
0.00	Virtually none of the trees are conifers.	Virtually none of the trees are ponderosa pine (i.e., ponderosa pine is not mentioned in the summary description).

The LANDFIRE project primarily was concerned with mapping forest canopy (i.e., in the final product, forest canopy supersedes shrub or grass canopy, such that any pixel with more than 10% canopy of trees is given a percent tree cover estimate, even though the remaining 90% of the pixel could be a combination of shrubs or herbaceous plants). Although we had complete LANDFIRE shrub cover estimates for the whole state, we had less faith in the accuracy of these estimates than we did for LANDFIRE forest cover. Therefore, for the shrub variables we weighted LANDFIRE canopy cover estimates equally with ecological system scores, resulting in the following formula:

*Index = GAP Ecological System Score * LANDFIRE Percent Shrub*

As an example of ecological system scores for shrub types, assume a system is 50% shrub, 25% grass and 25% barren, while 50% of the shrubs present are sagebrush. In this case the general shrub score would be 0.50, since half the system is dominated by shrubs. The sage score would also be 0.50 (rather than 0.25), because half of the shrubs are sagebrush (Table A4.7). Multiplying the GAP Ecological System score by the LANDFIRE shrub cover therefore nets the appropriate 25% cover of sagebrush. Note that shrubs include all non-tree woody vegetation (e.g., sagebrush, willow, alder, greasewood, saltbush, mountain mahogany, and serviceberry.

TABLE A4.7. ECOLOGICAL SYSTEM SCORE DEFINITIONS FOR SHRUB, HERBACEOUS, AND SAGEBRUSH INDICES

SCORE	*GENERAL SHRUBS ("SHRUB") OR HERBACEOUS ("HERB") -- SHRUB USED AS EXAMPLE BELOW*	*SAGEBRUSH ("SAGE")*
1.00	The tallest component of the system is shrub (i.e., no trees) and cover of shrubs is complete.	Virtually all of the shrubs in the system are sagebrush.
0.95	The tallest component of the vegetation is largely shrub, but the description notes occasional co-dominants or scattered occurrences of other vegetation (i.e., tree cover is <10% and shrub cover is >90%).	The dominant shrub species is largely sagebrush, but the description notes occasional co-dominants or scattered occurrences of other shrub species.
0.75	The tallest component of the vegetation is mostly shrub, but the description notes substantial co-dominants and regular occurrences of other vegetation (i.e., shrub cover is over 70%).	The dominant shrub species is sagebrush, but there can be a *substantial* portion of other shrubs (e.g., saltbush, greasewood) that co-dominate. For example: "*Artemesia* spp. typically dominates the canopy, although juniper trees can co-dominate and in some areas greasewood can form dense stands. "
0.50	Shrubs are the tallest component of the vegetation for roughly half the area of this system, the other half being any combination of trees, herbaceous or barren.	At least half the shrubs are <u>not</u> sagebrush. For example: "Sagebrush is the key indicator species, but several other woody shrubs are generally mixed in the canopy, including mountain mahogany and service berry."
0.25	About a quarter of the system is dominated by shrubs (i.e., where shrubs are the tallest vegetation). Forest habitats with a dense shrub understory and/or shrub inclusions might be given a score of 0.25.	Most of the shrubs are <u>not</u> sagebrush, but a *substantial* portion of sagebrush co-dominates. For example: "Greasewood or saltbush typically dominate this system, although in some areas sagebrush can form contiguous stands. "

Score	*General Shrubs ("shrub") or Herbaceous ("herb") -- Shrub used as Example below*	*Sagebrush ("sage")*
0.05	Shrubs are listed as a minor component of the ecosystem, often occurring in small pockets in otherwise forested, herbaceous or barren areas (i.e., < 10% shrub cover). Most habitats with a noteworthy shrub understory should be classified as at least 0.05.	Sagebrush occurs occasionally, or in small pockets. For example: "*Artemesia* species can occur in drainage bottoms ."
0.00	Virtually none of the system is dominated by shrubs.	Virtually none of the system is dominated by sagebrush. (i.e., *Artemesia* species are not mentioned in the description.)

The indices for tree and shrub cover generated as described above were then smoothed by calculating a Focal Mean using a 27 cell (approximately 800 m), circular neighborhood around each pixel. We chose 800 m because 95% of our input occurrence points had an spatial mapping precision of 800 m or better. Finally, these indices were rescaled such that they ranged in value between 0 and 1, where 0 indicates no cover of the target species or life form within 810 m, and 1 indicates continuous cover of the target species or life form within the 810 m window.

Herbaceous Cover Index ("herb")

To generate a layer from LANDFIRE Existing Vegetation Cover data showing the herbaceous percent cover, we first reclassified the LANDFIRE Existing Vegetation Cover layer (Table A4.8), to reflect our assessment of likely herbaceous cover associated with each class. The resulting reclassified layer was then multiplied by the GAP scored layer for herbaceous cover, smoothed using a circular 27-cell Focal Mean, and rescaled such that values ranged from 0 to 1. The herbaceous cover layer was part of the base predictor set, and was used in the final models for 33 species.

TABLE A4.8. ASSIGNED HERBACEOUS COVER FOR LANDFIRE EXISTING VEGETATION COVER CLASSES

LANDFIRE Existing Vegetation Cover Classname	*Assigned Herbaceous Cover*
Open Water	0.00
Snow/Ice	0.00
Developed - General	0.05
Developed - Open Space	0.30
Developed - Low Intensity	0.20
Developed - Medium Intensity	0.10
Developed-High Intensity	0.00
Barren	0.00
Quarries-Strip Mines-Gravel Pits	0.00

Agriculture - General	0.10
Pasture/Hay	0.40
Cultivated Crops	0.10
Small Grains	0.20
Fallow	0.40
Sparse Vegetation Canopy	0.10
Tree Cover >= 10 and < 20%	0.00
Tree Cover >= 20 and < 30%	0.05
Tree Cover >= 30 and < 40%	0.05
Tree Cover >= 40 and < 50%	0.05
Tree Cover >= 50 and < 60%	0.05
Tree Cover >= 60 and < 70%	0.05
Tree Cover >= 70 and < 80%	0.05
Tree Cover >= 80 and < 90%	0.05
Tree Cover >= 90 and <= 100%	0.05
Shrub Cover >= 10 and < 20%	0.05
Shrub Cover >= 20 and < 30%	0.05
Shrub Cover >= 30 and < 40%	0.05
Shrub Cover >= 40 and < 50%	0.05
Shrub Cover >= 50 and < 60%	0.05
Shrub Cover >= 60 and < 70%	0.05
Shrub Cover >= 70 and < 80%	0.05
Shrub Cover >= 80 and < 90%	0.05
Shrub Cover >= 90 and <= 100%	0.05
Herb Cover >= 10 and < 20%	0.15
Herb Cover >= 20 and < 30%	0.25
Herb Cover >= 30 and < 40%	0.35
Herb Cover >= 40 and < 50%	0.45
Herb Cover >= 50 and < 60%	0.55
Herb Cover >= 60 and < 70%	0.65
Herb Cover >= 70 and < 80%	0.75
Herb Cover >= 80 and < 90%	0.85
Herb Cover >= 90 and <= 100%	0.95

For land cover variables that were generated using a different process than that outlined in the section above (i.e., Percent Forest Cover, Forest Cover Index, Pinyon-Juniper Index, and Bare Ground Index), the process used to generate them is described below, under the appropriate headers.

Percent Forest Cover ("frstc")

The percent forest cover layer we used in modeling was produced by resampling the LANDFIRE Forest Canopy Cover layer to the projection, cell size and alignment, and extent of our other predictor data, using a Nearest Neighbor resampling. The resulting dataset contains values from 15 to 95 representing the midpoints of the 10 percent canopy cover classes (e.g. 10% to 20%, 20% to 30%) present in the LANDFIRE dataset. Areas below 10% in the LANDFIRE Forest Canopy Cover dataset are simply referred to as "Non-Forested," and were given a value of 0 in our percent forest cover variable dataset. This layer was used in the base set of predictors, and was included in 18 species' final models

Forest Cover Index ("frst")

In order to produce a variable with the same smoothing effect as the land cover layers described above (e.g., the Ponderosa Pine Index), we applied the same 27-cell, circular Focal Mean routine to the Percent Forest Cover ("frstc") layer described above. We then rescaled the resulting, smoothed layer such that the values stretched from 0 (no forest cover in 800 m window surrounding) to 1 (complete forest cover in 800 m window surrounding). This layer was included in the set of base predictors, and was included in the final models for 37 species.

Pinyon-Juniper Index ("pj")

In testing methods for producing a Pinyon-Juniper index, we felt that the LANDFIRE Forest Canopy Cover layer was less reliable for areas with relatively low percent cover of trees, such as those areas that typify much of the Pinyon-Juniper landscape. For this reason, we calculated the Pinyon-Juniper index solely based on the GAP Ecological System score (Table A4.5), to produce a layer with values ranging from 0 (no cover of Pinyon-Juniper) to 1 (entirely dominated by Pinyon-Juniper). As with the other land cover variables, we then applied a 27-cell, circular Focal Mean routine on this layer, and rescaled the values in the resulting, smoothed layer such that they ranged from 0 to 1. This predictor was included in the base set of predictors, and appeared in the final models for 39 species.

Bare Ground Index ("bare")

To generate an index that estimates percent bare ground across the state, we first summed the values for percent tree cover, shrub cover, and herb cover from the LANDFIRE Existing Vegetation Cover layer to create a layer representing total vegetative cover. We subtracted this layer from a constant value of 1.05 (the maximum value in this summation layer), and rescaled the result to create an index between 0 (no bare ground) and 1 (100% bare ground). This layer assigned a bare ground cover of 100% for any developed or other non-natural system, which is not accurate in most cases (e.g., most "Pasture/Hay" has a bare ground percent cover closer to 0) . Thus, we reclassified LANDFIRE Existing Vegetation Cover for these non-natural classes to reflect values we felt were more representative of actual bare ground cover (Table A4.9). Where the previously generated bare ground layer had values of 0 (any developed or modified type), we "burned in" the assigned bare ground cover values. Finally, we smoothed the resulting bare ground layer using a 27-cell, circular Focal Mean, and rescaled the resulting layer so that values ranged from 0 (no bare ground) to 1 (100% bare ground). This layer was included as a potential predictor in the base predictor set used for all species, and was used in the final models for 14 species.

Table A4.9. Assigned Bare Ground Cover for LANDFIRE Existing Vegetation Cover Classes

Existing Vegetation Cover CLASSNAMES	*Assigned Bare Ground Cover*
Open Water	1.00
Snow/Ice	1.00
Developed - General	0.90
Developed - Open Space	0.50
Developed - Low Intensity	0.75
Developed - Medium Intensity	0.90
Developed-High Intensity	1.00
Barren	1.00
Quarries-Strip Mines-Gravel Pits	1.00
Agriculture - General	0.75
Pasture/Hay	0.50
Cultivated Crops	0.75
Small Grains	0.75
Fallow	0.50
Sparse Vegetation Canopy	0.90

Percent Cover of Sagebrush ("usage")

The "percent cover of sagebrush" layer was created by modifying the USGS' sagebrush habitat model (Homer et al. 2009) to eliminate "No Data" areas in the original dataset. To do this, we reclassified areas classified as "101" in the original dataset as "0," as these are generally areas where no sagebrush occurs, and reclassified areas classified as "102" in the original dataset as "No Data," as these were areas outside the extent of the original mapping. This layer was not included in the base set of predictors, but was added in as a potential predictor for species where percent sagebrush cover was deemed an important factor. Percent sagebrush cover was used as a predictor in the final models for 3 species.

Distance to Permanent Snow ("d2snow")

For species whose distribution is associated with permanent snowfields, such as rosy-finches, we generated a "distance to permanent snow" layer. We did this by selecting areas classified as "North American Alpine Ice Field" in the GAP land cover layer (Gap Analysis Program 2010) or as "Snow/Ice" in the LANDFIRE Existing Vegetation Cover layer (Comer et al. 2003), combining these features, and then calculating the Straight Line distance, in meters, to the nearest of these features, using ArcToolbox. This layer was not part of the base set of predictors, but was added in as needed for selected species. This variable was used in the final models for 2 species.

LANDSCAPE STRUCTURE

CONTAGION ("CONTAG")

Contagion measures the dispersion and interspersion of landscape patches (O'Neill et al. 1988; Li and Reynolds 1993), and provides meaningful information on fine-scale habitat patterns (see Turner 1989). We used Fragstats (McGarigal and Marks 1994) to calculate a contagion index for Wyoming. To calculate contagion, Fragstats requires a raster dataset with multiple classes of patches (i.e., habitat types). We therefore reclassified the Existing Vegetation Cover layer from the LANDFIRE dataset into four patch categories (Table A4.10). We used an 800 m radius, round, moving window to calculate contagion on this reclassified patch layer. The contagion index was included in the base set of predictors examined for all species.

TABLE A4.10. PATCH CATEGORIES USED TO DERIVE CONTAGION INDEX

PATCH CATEGORY	*LANDFIRE EVT CLASSNAME (EVT RASTER VALUE)*
Barren	Open Water (11), Snow/Ice (12), Developed - General (20), Developed - Low Intensity (22), Developed - Medium Intensity (23), Developed-High Intensity (24), Barren (31), Quarries-Strip Mines-Gravel Pits (32), Agriculture - General (80), Cultivated Crops (82), Small Grains (83), Sparse Vegetation Canopy (100)
Herbaceous	Developed - Open Space (21), Pasture/Hay (81), Fallow (84), Herb Cover >= 10 and < 20% (121), Herb Cover >= 20 and < 30% (122), Herb Cover >= 30 and < 40% (123), Herb Cover >= 40 and < 50% (124), Herb Cover >= 50 and < 60% (125), Herb Cover >= 60 and < 70% (126), Herb Cover >= 70 and < 80% (127), Herb Cover >= 80 and < 90% (128), Herb Cover >= 90 and <= 100% (129)
Shrub	Shrub Cover >= 10 and < 20% (111), Shrub Cover >= 20 and < 30% (112), Shrub Cover >= 30 and < 40% (113), Shrub Cover >= 40 and < 50% (114), Shrub Cover >= 50 and < 60% (115), Shrub Cover >= 60 and < 70% (116), Shrub Cover >= 70 and < 80% (117), Shrub Cover >= 80 and < 90% (118), Shrub Cover >= 90 and <= 100% (119)
Tree	Tree Cover >= 10 and < 20% (101), Tree Cover >= 20 and < 30% (102), Tree Cover >= 30 and < 40% (103), Tree Cover >= 40 and < 50% (104), Tree Cover >= 50 and < 60% (105), Tree Cover >= 60 and < 70% (106), Tree Cover >= 70 and < 80% (107), Tree Cover >= 80 and < 90% (108), Tree Cover >= 90 and <= 100% (109)

DISTANCE TO PRIMARY AND SECONDARY ROADS ("D2ROAD")

As many species are sensitive to the disturbance caused by roads (e.g, Forman and Alexander 1998), we created a "distance to roads" layer by calculating the Straight Line Distance (in ArcToolbox) to primary or secondary roads in the TIGER Line Files (U.S. Census Bureau 2005;Table A4.11). "D2ROAD" was initially included in the base set of predictors, but was later excluded from the base set, as many species' occurrence data locations are close to roads, due to survey bias. This predictor was not used in the final models for any species.

TABLE A4.11. ASSIGNED CATEGORIES FOR TIGER ROAD DATA

TIGER CFCC CODE	*ASSIGNED CATEGORY*
A11, A13, A15, A17, A18, A21, A23, A25, A27, A63, A31, A33, A35, A38, A60, A00, A64	Primary
A41, A43, A44, A45, A47, A48, A62, A66, A67, A70, A73, A74	Secondary
All other codes	Not used

HUMAN FOOTPRINT ("DSTRB")

Roads do not represent the sole human disturbance that can impact species' distributions: mines, wells, pipelines, residential development, and agriculture also plan an important role. We used The Nature Conservancy's (TNC) "Landscape Integrity" layer, which was produced by calculating the Euclidean distance to various human disturbances (Copeland et al. 2007), with minor modifications. TNC's layer gave a distance value of "No Data" to the areas of disturbance themselves (i.e., roads, wells, surface mines, etc). As Maxent will not generate a prediction surface for any location where the predictor layer has no value (i.e., "No Data" areas), we replaced these "No Data" values with values of "0," to indicate a distance of 0 m to disturbance. As with "distance to roads," the human footprint layer was not included in the base set of predictors, since species' observations may be artificially biased toward areas classified as disturbed areas, such as cities. The layer was included in the variable reduction model run for a limited number of species where human disturbance has a known detrimental effect (e.g., gray wolves, grizzly bears), but was not used in any species' final models.

SUBSTRATE

Substrate, including soil and bedrock geology, and influence species' distributions both directly and indirectly. For example, soil texture, composition, and depth can limit burrow construction, soil chemistry can shape plant communities, and bedrock geology can combine with topography to create specific habitat features such as caves. We combined expert knowledge with existing soil and bedrock geology layers to create predictor layers representing these substrate attributes.

DEPTH TO SHALLOWEST RESTRICTIVE LAYER ("D2SRL")

Burrowing animals may be restricted in their distribution by soil depth. To create a predictor layer that captures soil depth, we first used the National Resource Conservation Service's (NRCS) Soil Data Viewer 5.1, using STATSGO data, with the "Dominant Component" option selected, and with the "Restriction Kind" set to "Bedrock (Lithic)." We exported this layer, representing the depth to shallowest lithic bedrock by soil map unit, as a new feature class. Next, we repeated the previous step with the same options and settings, but selecting "Bedrock (Paralithic)" as the "Restriction Kind," and exported this to a new feature class. Finally, we used a tabular summary process to find the minimum value between the first and second feature class by soil map unit, to create the "depth to shallowest restrictive layer" predictor. This layer was part of the base predictor set, and was used in the final models for 27 species.

Soil - Fraction Clay ("fclay") and Fraction Sand Content ("fsand")

As with soil depth, fraction clay and fraction sand content may also impact the distribution of burrowing animals. We used fraction clay content and fraction sand content layers generated previously by WYNDD from STATSGO data (unpublished data), using a modified version of AGWA 1.31 (see current versions at http://www.tucson.ars.ag.gov/agwa/index.php/home-mainmenu-1), an extension to ArcView 3.x. NRCS' Soil Data Viewer can be used to generate similar data layers from STATSGO data or from SSURGO data, where available. These two texture variables were not included in the base predictor set, but were included as potential predictors for species where soil texture may play an important role. Fraction sand content was included as a predictor in the final models for 4 species; clay content was not included in any species' final models.

Soil Texture ("soltxt")

A categorical soil texture variable was also generated (originally for the northwestern U.S., and later clipped to match the extent of the other predictors used here) with the "Surface Texture" mapping tool in Soil Data Viewer (SDV) 5.1, using the "Dominant Condition" aggregation method. This produced a map of soil textures with approximately 80 values, which were then condensed, through reclassification, into 6 ordinal texture classes, from finest to coarsest (Table A4.12). Water was lumped with category "0," the finest category, as all pixels in each predictor layer must have a value for use in Maxent. The soil texture variable was not included in the base predictor set, but was included as a potential predictor for selected species. Soil texture appeared in the final models for 5 species.

Table A4.12 Soil Texture Class Reassignment from Soil Data Viewer Types

Surface Texture Class from SDV	*Class in "soltxt" Layer*
Clay, muck, peat, silty clay	0 (Finest)
Channery loam, cobbly loam, gravelly loam, loam, mucky silt, slightly decomposed plant material, stony loam, stratified silty clay loam to clay, very channery loam, very cobbly loam, very gravelly loam, very stony loam, channery clay loam, clay loam, cobbly clay loam, extremely cobbly loam, extremely stony loam, gravelly clay loam, very cobbly clay loam, very stony clay loam	1
Ashy silt loam, channery silty clay loam, cobbly silt loam, extremely gravelly clay loam, extremely stony clay loam, fine gravelly silt loam, fine sand, gravelly silt loam, silt loam, silty clay loam, stony silt loam, variable, very cobbly silt loam, very gravelly silt loam, very stony silt loam, very stony silty clay loam, extremely cobbly silt loam, extremely stony silt loam, extremely stony silty clay loam, gravelly ashy sandy clay loam, gravelly sandy clay loam, sandy clay loam	2
Channery fine sandy loam, coarse sandy loam, fine sandy loam, gravelly fine sandy loam, sand, very channery fine sandy loam, very cobbly very fine sandy loam, very fine sandy loam, very gravelly fine sandy loam, gravelly sandy loam, loamy fine sand, loamy very fine sand, sandy loam, very channery sandy loam, very cobbly sandy loam, very gravelly ashy sandy loam, very gravelly sandy loam, very stony sandy loam	3

Extremely stony sandy loam, fine gravelly coarse sandy loam, gravelly coarse sandy loam, gravelly loamy sand, loamy sand, very cobbly loamy sand, very gravelly loamy sand, very stony loamy sand	4
Consolidated permafrost (ice rich), extremely gravelly loamy sand, fragmental material, unweathered bedrock, cobbly loamy coarse sand, gravelly loamy coarse sand, loamy coarse sand	5 (Coarsest)

Distance to Cave-Forming Formations ("d2cave")

There is currently no comprehensive cave mapping for Wyoming in GIS format (W. Sutherland, pers. comm.), so we instead generated a "cave potential" layer based on the solubility of bedrock geology units. To do this, we first selected bedrock geology units from the 250k Bedrock Geology layer for Wyoming (Love and Christiansen 1985) where the unit description included a reference to one of the four soluble types described by Hill et al. (1976): limestone, dolomite, gypsum, and anhydrite. We then reclassified the bedrock geology units as a binary layer representing the potential for cave-formation. We further revised this binary map per comments from Wayne Sutherland of the Wyoming State Geological Survey. Finally, we calculated Straight Line Distance in ArcToolbox to the bedrock geology units we identified as having the potential to form caves, resulting in our final "distance to caves" layer. This layer was not used in the base set of predictors; rather, it was added as a potential predictor for species associated with caves. "d2cave" appeared in 5 species' final models.

Elevation ("elev")

Raster tiles of the National Elevation Dataset (NED; Gesch et al. 2009) at 1-arc-second resolution were downloaded from the National Map Seamless Server (http://seamless.usgs.gov/) and mosaicked to cover Wyoming, plus a 5,000 m buffer surrounding the state. This layer was then projected to the WYLAM projection and resampled to 30 m spatial resolution, to serve as the basis for all other predictor layers. Elevation was included in the base set of predictors, and was included in the final models for 32 species.

Degree Slope ("slope")

Slope data were derived from the 30 m resampled elevation layer using the "Slope" function with the "Degree" option in ArcToolbox. Slope was included in the base set of predictors, and was included in the final models for 12 species.

8-Category Aspect ("asp8")

A slope aspect layer was generated using the "Aspect" function with the "elev" dataset in ArcToolbox. Because aspect is a circular variable (i.e., 0° represents the same aspect as 360°), it is generally transformed into a categorical predictor before it is used in modeling. We therefore classified aspect into eight aspect categories centered on cardinal and primary intercardinal directions, plus a "flat" category for areas of with a slope of 0 (Table A4.13). This variable was not included in the base set of predictors across all species, as we found categorical variables to be problematic when there are a limited number of sample occurrences. Instead, the continuous variables, "aprime" and "radld" (see below), were used to capture any slope aspect signal present in the species occurrence data. The 8-category aspect layer was not included in the final models for any species.

Table A4.13. Assigned Slope Aspect Categories

Aspect Raster Value	Aspect Range	Category
-1	-1	Flat
0	337.5° - 360°; 0° - 22.5°	North
1	22.5° - 67.5°	Northeast
2	67.5° - 112.5°	East
3	112.5° - 157.5°	Southeast
4	157.5° - 202.5°	South
5	202.5° - 247.5°	Southwest
6	247.5° - 292.5°	West
7	292.5° - 337.5°	Northwest

A' (Transformed Aspect; "aprime")

The slope aspect layer was also transformed to create a unit-less index known as A' (A-prime) that ranges from 0.0 to 2.0 along a southwest to northeast axis, respectively (Beers et al. 1966). A' describes a pronounced temperature and moisture gradient that occurs along this axis (Urban et al. 2000). This layer was included in the base set of predictors, and appeared in 2 species' final models.

Radiation Load ("radld")

The impact of slope aspect on incident radiation depends upon the slope (i.e., steep southwest aspects should be drier than southwest aspects with a more gentle slope). Thus, A' was multiplied by degrees slope and subtracted from 180 to create a unit-less radiation load index ranging from 0 (lowest) to 180 (highest). This index has been used to predict vegetation dynamics at a fine scale by identifying a moisture gradient not readily quantified using other metrics (e.g., Andersen and Baker 2006). "Radld" was included in the base set of predictors evaluated for all species, and was used in the final models for 2 species.

Vector Ruggedness Measure ("vrm11")

We ran a python script developed by Mark Sappington (available at http://arcscripts.esri.com/details.asp?dbid=15423) on the 30 m elevation layer, using an 11-pixel neighborhood, to generate an index of terrain ruggedness. This index is relatively independent from slope, and has been used to construct models for species such as bighorn sheep that require rugged terrain (Sappington et al. 2005). We tested a variety of neighborhood sizes, including the 3-cell neighborhood described by Sappington et al. (2005). However, a neighborhood of 11-cells appeared to best represent our notion of ruggedness in Wyoming at a scale we felt was meaningful to species' distributions. "VRM11" was included in the base set of predictors, and appeared in the final models for 18 species.

Compound Topographic Index ("cti")

To capture small surface water features that may not be captured in hydrography datasets, we calculated an index called the "Compound Topographic Index" (CTI; Gessler et al. 1995), using an Avenue script created by Paikho Rho (available at http://arcscripts.esri.com/DETAILS.ASP?DBID=12223) in ArcView 3.2. Also known as the "steady-state wetness index," this index is generally defined as the ratio of catchment area to slope, and is useful in predicting soil and moisture availability characteristics that can influence vegetation (e.g., Andersen and Baker 2006). "CTI" was included in the base predictors set, but was ultimately excluded from subsequent models, as it appeared to magnify artifacts present in the NED data used to generate it.

Landform Classification ("lf_10_20")

Andrew Weiss (2001) provided a method for classifying the landscape into a set of landforms using the Topographic Position Index (TPI). We used an ArcView 3.x implementation of this method (Jenness 2006) to classify Wyoming into landforms. We used circular small and large neighborhood sizes of 10 and 20 pixels, respectively, to calculate the TPI values, and used the default landform classification provided by the tool. As with the Vector Ruggedness Measure, we experimented with a number of neighborhood sizes, and found that the 10 and 20 pixel neighborhoods provided a classification that most closely matched our desired results for selected reference areas in the state. This predictor was not included in the base set of predictors, nor was it included in the final models for any species, as categorical variables appeared to lead to overfitting in Maxent when a small number of sample points were used.

Potential For Rock Outcrop ("lfoutc")

While many species make use of rock outcrops for some portion of their life cycle (e.g., basking reptiles, nesting raptors, bighorn sheep), no GIS layer representing rock outcrops exists for the state of Wyoming (F. McLaughlin, pers. comm.). We examined a number of possible methods for efficient mapping of potential rock outcrop areas, including identifying areas of steep slope, areas classified as "barren" or some similar type in existing land cover maps, using topographic ruggedness, and looking for deeply shaded areas in hillshade layers. None of these methods consistently identified known rock outcrops in reference areas of Wyoming as identified in reptile surveys and other field data.

Image interpretation or classification techniques likely would provide an accurate way to identify rock outcrops, but would require an intensive and lengthy effort to generate. Instead, we used the landform classification tool described above, with small and large circular neighborhoods of 3 and 10 cells, respectively, and selected those areas classified by the tool as "Mountain Tops, High Ridges" or "Upper Slopes, Mesas" as potential rock outcrop areas and reclassified the layer into a binary rock outcrop layer. This classification appeared to yield good results for our reference areas, identifying areas of rock outcrop mapped in reptile survey data and those clearly visible in aerial photography, while minimizing overprediction of these features. Since species using rock outcrops may be observed or mapped in areas adjacent to the outcrops, rather than directly on the outcrops, we used the Straight Line Distance tool in ArcToolbox to generate our final "lfoutc" layer, which represents the distance, in meters, to nearest mapped rock outcrop. This layer was included in the set of base predictors, and was used in the final models for 7 species.

Distance to Cliffs ("d2clif")

Presence of cliffs can be important to the distribution of species such as bats and some raptors However, no existing GIS layer captures these features in a comprehensive way throughout the state of Wyoming. As such, we generated a "distance to cliff" layer as a proxy for this information. To identify likely cliffs, we first reclassified our slope layer into a binary layer representing cliffs, specifying potential cliffs as areas with a slope greater than 40°. This produced a large number of scattered pixels that in many cases represented either noise in the elevation dataset or potential rock outcrops that did not appear to be cliffs as we defined them. Thus, we used the Neighborhood Focal Statistics tool in ArcToolbox, with a 5 cell x 5 cell, rectangular neighborhood, calculating the Majority statistic, on the binary "potential cliffs" layer. This spatial filter eliminated scattered pixels representing noise or very small outcrop features, but maintained cliffs we identified as reference areas (e.g., Bighorn Canyon). Finally, we calculated the Straight Line Distance, in meters, to these filtered cliff areas using ArcToolbox, to generate our final "Distance to Cliffs" layer." This was done because even species that depend upon cliffs may have occurrences located some distance away from cliffs, either because of imprecision in mapping the occurrence, or because the species was found away from cliffs while foraging or during some other daily or seasonal activity that does not happen along the cliffs themselves. This predictor was not included in the base set of predictors, but was added as a potential predictor for selected species, and was used in the final models for 3 species.

OTHER VARIABLES

Predicted Prairie Dog Distribution ("pdog")

For two species (burrowing owl and black-footed ferret), prairie dog colonies are a key aspect influencing the species' distributions. We combined the final, logistic models for both black-tailed and white-tailed prairie dogs, using a Local Maximum function, to produce a layer that provides an index of the likelihood of occurrence for either prairie dog species. We investigated the resulting layer as a potential predictor for burrowing owl and black-footed ferret, but found that other predictors were more powerful for these two species. Thus, the "pdog" variable was not used in any final models.

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