Predicted Spatial Variation in Density of Golden Eagle Nest Sites in the Western United States: Guidance for Conservation Applications

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Modeling Overview

We developed spatially explicit models of golden eagle nest site density with the goal of providing reliable planning and decision support tools to inform conservation planning and project evaluation (Dunk et al. 2019). Models were created in a presence-available modeling framework using >6,500 known nest site locations. Relative nest site density was modeled independently for twelve distinct regions, and projected to three additional regions, for ca. 3,560,000 km^2 (1,380,000 mi^2) of the western United States. The models are publicly available for application in regional and landscape-scale conservation planning. Application of the models to specific golden eagle conservation-related questions requires a thorough understanding of model characteristics and limitations, appropriate scales for drawing inference, and in some instances, federal policies and guidance governing implementation of the Bald and Golden Eagle Protection Act.

The objective of this document is to describe the model products and provide guidance for their use. We describe the available model products and map surfaces, as well as the following broad categories of model applications: 1) use for visual evaluation of golden eagle nest site density within modeling regions; 2); quantitative comparison of golden eagle nest site density between or among modeled areas; 3) risk analysis; 4) planning of development projects; and 5) integration with other spatial decision-support tools and modeling platforms. We conclude with caveats and limitations related to accuracy and reliability, comparing model predictions among regions, appropriate scales for application, and model interpretation and inference. Our intent is to make these modeling products available and useful to land managers and other scientists, regardless of their background or experience with models like these.

Model Products

Model products are publicly available for download on ServCat, including high-resolution maps, geospatial data, and related publications and documentation. Models available on ServCat are considered final versions. Revision and refinement of these models may occur in the future as new data generated from surveys, telemetry studies, and field application become available.

Maps of Model Predictions

The final relative nest site density model (RND) output map surface (raster) is represented by 120 x 120-m pixels with values ranging from 0 to 1. All subsequent map products were based on this surface. To facilitate direct comparisons of predicted density of nest sites within a modeling region, we created an additional raster surface, Area-Adjusted Frequency (AAF), which is available as both a continuous and classified map layer.

1) **Relative Nest Site Density (RND)** – The raw RND map shows continuous values of relative nest density within each modeled region, from 0 to 1. This map accurately displays the distribution of predicted RND at fine scales and is valuable for detailed visualization of the raw model output.
2) **Area-adjusted Frequencies (AAF)** –AAF represents the extent to which the number of golden eagle nest sites differs from a random distribution of nests within each modeled region. AAF values <1 represent lower than random densities, and AAF values >1 represent greater than random densities. AAF was estimated for overlapping, equal-interval bins of RND values (0-0.10, 0.01-0.11,…0.90-1) across the full range of values in each RND raster (up to 91 bins for models with a RND range of 0-1). The resulting table of AAF estimates (provided in metadata on ServCat) was then used to reclassify the RND raster to AAF values (Table 1), and this AAF surface was then smoothed to the approximate scale of golden eagle nesting core-use areas (see Methods in Bedrosian et al. *In press*) to provide a more biologically relevant depiction of eagle presence relative to breeding habitat. This surface is most appropriate for risk analyses (e.g., relative risk of electrocution, Bedrosian et al. *In press*) and comparing predicted densities of golden eagle nesting sites between or among areas.

Table 1. Table used to reclassify the Relative Nest Density (RND) surfaces to Area-adjusted Frequencies (AAF). Output values shown are for a hypothetical example with RND values ranging 0-1, and are different for each model's unique RND surface.

From Value (RND)	To Value (RND)	Reclass To Output Value (AFF)	RND Bin For AAF Calculation
0.00	0.05	0.116	0.00-0.10
0.05	0.06	0.125	0.01-0.11
0.06	0.07	0.163	0.02-0.12
…	…	…	…
0.92	0.93	46.128	0.88-0.98
0.93	0.94	48.395	0.89-0.99
0.94	1.00	52.560	0.90-1.00

3) **Area-adjusted Frequencies (AAF) Categories** – The raw AAF surfaces were reclassified into descriptive categories (Table 2) to provide an easily interpretable visualization of the relative differences in the densities of golden eagle nests. This map is most appropriate for visual evaluation of golden eagle nest density and eagle presence within an area of interest.

Table 2. Table used to reclassify Area-adjusted Frequencies (AAF) surfaces to AAF categories for all models.

From Value (AAF)	To Value (AAF)	Reclass To Output Value (AAF Category)
0.000	0.083	1 very low density
0.083	0.200	2 low density
0.200	0.500	3 moderate-low density
0.500	2.000	4 neutral density
2.000	5.000	5 moderate-high density
5.000	12.000	6 high density
12.000	∞	7 very high density

Model Applications

Visual Evaluation of Nest Site Density

Raster surfaces and map products can be used for visual evaluation of relative golden eagle nest site density estimates within an area of interest. High resolution AAF maps are useful for visually evaluating the spatial distribution of golden eagle nest site density as well as understanding the magnitude of differences in nest site density among areas within a modeling region. GIS users can access the geospatial data to produce maps and conduct spatial analyses at smaller scales for their area of interest.

Comparing Predicted Golden Eagle Densities

Within a modeling region, AAF values provide direct comparisons of golden eagle nesting density estimates between/among RND bins. The ratio of AAF values (any RND bin's AAF value divided by AAF of another bin) provides an estimate of the magnitude of difference in golden eagle nest site densities between those RND bins. For example, an AAF value of 15 can be interpreted as five times the expected density of golden eagle nest sites as an AAF value of 3. Within all modeling regions, we found very large differences in nest site densities between the lowest and highest RND bins, ranging from 131.6–2,660.4 times greater densities in the highest bins than the lowest (see Dunk et al. 2019). Two areas of interest, such as project assessment areas, could be compared using a ratio of the summation of AAF values within each polygon. Further insights could be gained by comparing the spatial and numerical distributions of AAF between assessment areas, such as if the area is predicted to be generally low density but with "hot spots" or if golden eagle nest site density is more evenly distributed within the area.

Risk Analysis

Our models of golden eagle nest site density can be used to predict spatial overlap of predicted nest site density to proposed or actual stressors and identify areas predicted to have lower or higher relative risk of reduced survival or reproductive success caused by a specific stressor. Because model predictions represent relative density of nest sites and not the distribution of eagle presence or density of use, our models' use in risk analyses should not be interpreted as a direct estimation of eagle exposure to risk. Spatial prediction of relative risk across regions or landscapes can be determined by the overlap between golden eagle relative nest site density (exposure) models and models or indices of hazards, such as electrocution or lead poisoning. Relative risk maps, areal calculations, and a discussion on applying WGET's risk analysis products are provided in Bedrosian et al. (*In press*) and incorporated into WGET's Ecoregional Conservation Strategies. These risk analyses can be used to inform conservation planning, targeted mitigation, land acquisition, energy development, etc. by ranking areas based on the predicted relative density of eagle nesting sites and predicted or actual distribution of a hazard.

Planning of development projects

When projected as maps depicting relative density of golden eagle nest sites, our models provide a regional- and landscape-scale analysis tool for proactive planning of development projects that could potentially affect eagles. This is valuable for a variety of land-use planning activities ranging from siting recreational vehicle trails on public lands to energy infrastructure projects, and energy development (particularly wind energy development). Our models are ideally suited for landscape-scale 'desktop' analyses, described as Stage 1 in federal guidance for wind energy development, as an initial step in assessing and comparing potential development areas. The cost and time investment for landscape-scale surveys to support these assessments can be prohibitive, making use of a model-based framework an effective and efficient means to identify areas of relatively high risk for more detailed study or targeted field surveys.

Integration with other spatial decision-support tools and modeling platforms

The golden eagle relative nest site density models are suitable for integration with a wide variety of spatial decision-support tools for conservation. For example, the model surfaces can be adapted for integration with the Western Association of Fish and Wildlife Agencies (WAFWA) Crucial Habitat Assessment Tool. At larger scales, our models can be used to integrate golden eagle nest site density into ecosystem- or regional-scale conservation planning. Large-scale planning efforts (e.g., WAFWA Sagebrush Ecosystem Initiative) benefit from multi-species information to inform spatial prioritization of conservation actions. Our nest site density models can also serve as spatial layers in models to evaluate and compare the relative effectiveness of alternative golden eagle conservation and/or development scenarios at regional or larger scales. Our models can also be used as input for reserve prioritization software, such as Marxan and Zonation, to identify areas where the highest and lowest quality habitats are concentrated.

Caveats and Limitations

Accuracy and Reliability

The golden eagle nest site density models are robust and well calibrated to real spatial variation in golden eagle nest site density. For each of the 12 modeling regions, model predictions were consistent with the distribution of presence data in the evaluation data set, and in no cases did models predict extremely small or large numbers of nest sites when the opposite was observed (see Dunk et al. 2019 for detailed evaluation results). Deviations between predictions and withheld data were greatest for the Columbia Plateau, Southwestern Plains, California Foothills, and Chihuahuan Desert modeling regions, which had some of the smallest sample sizes of nest sites. Independent data were available to evaluate nine modeling regions and two projection regions, and model predictions were generally consistent with the independent observations. Variation in model performance among regions was largely related to variation in sample size and dispersion patterns of thinned nest sites. In general, as sample size increased model predictive power increased, and models were more robust.

Our models were developed to support conservation planning, and we recommend that models should be refined when improved data become available. In the course of compiling and analyzing golden eagle nest site data, we identified areas with few surveys or nest records for model training and in some cases (California Foothills, Columbia Plateau, and Southwestern Plains) developed models that are useful but would likely be improved with a larger, more spatially balanced training sample of nest sites.

Comparing Model Predictions Among Regions

Because we developed models separately for each modeling region, relative nest density values (RND, AAF) from individual regions are not directly comparable among regions, or across larger regional systems such as Bird Conservation Regions or Flyways. Each model's results are relative only to other areas within the same region. For larger-scale (e.g., state- or west-wide) conservation planning, standardization of values among regional models is necessary. An example of a standardization approach is the use of observed density of training nest sites among RND bins.

Appropriate Scales for Application

Use of our models in conservation applications is constrained by the spatial scale at which the models are applied. The base resolution of our models is 120-m (1.44-ha) pixels, but evaluation of, at least, thousands of pixels is necessary before meaningful comparisons of nest site density can be made. Our models are therefore intended for application at regional (millions of ha; e.g., ecoregions, or Bird Conservation Regions), landscape (thousands of ha; e.g., subunits of ecoregions, National Forests, Bureau of Land Management districts, National Parks, large valleys and basins), and project assessment area (thousands of hectares) scales; and should not be used to evaluate variation in RND at the scale of a small project (hundreds of ha). Model resolution is likely not appropriate for applications at finer scales, such as siting individual wind turbines within a project area, or evaluating the potential impact of relatively small scale (<1,000 ha) projects.

Model Interpretation and Inference

Relative density models do not represent estimates of probability of occurrence or absolute abundance. Although our relative density models can estimate the magnitude of difference in golden eagle nest densities among various areas, they do not estimate density per se. It is inappropriate to use our models by themselves for estimating actual (as opposed to relative) abundance of eagles for use in (for example) estimating eagle exposure in a collision risk model to predict collision fatalities at wind energy facilities, or estimation of mortality offset by a proposed compensatory mitigation project. Given an estimated or hypothetical number of nest sites or territories within a landscape or region, however, our models can be used to predict how those nest sites would be distributed.

From an ecological perspective, it is important to recognize that our models represent only golden eagles associated with nesting areas, not the full range of habitats used by non-breeding, wintering, or migrating eagles. Other models and spatial information representing different age classes of golden eagles, behaviors, or seasonally specific densities are necessary to support inferences regarding distribution and density of non-territorial golden eagles. Furthermore, in circumstances where higher quality local information from surveys exists, such information should be used *in lieu* of, or in combination with, our modeled predictions.

References

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