RaptorMapper: Wyoming Golden Eagle Decision Support Tool (DST)

Definition of Terms:

AAF – Area Adjusted Frequencies. AAF values represent relative density of locations (or intensity of use) in Wyoming. For the nesting model, AAF refers to relative density of Golden Eagle nesting areas, and for the non-nesting, fall migration, and spring migration models, AAF refers to relative density of locations (based on Golden Eagle telemetry data). AAF values were estimated from the MaxEnt model results. We binned the output into 10 equal-sized bins (0-0.1, 0.1-0.2, 0.2-0.3, etc.) and estimated the proportion of the modeling area that each bin is estimated to compose. AAF is equal to the proportion of training locations in bin x divided by the proportion of the modeling area in bin x. Values of 1.0 exist when both proportions are equal, values <1.0 occur when proportion of locations is less than proportion of area, and values >1.0 occur when proportion of locations is greater than proportion of area. Furthermore, dividing one bin's AAF value into another's provides an estimate of the magnitude of difference in density between those bins (see Dunk et al. 2019). For example, if bin *i* had an AAF = 0.2, and bin *m* had an AAF of 5, bin *m* is estimated to have a 25 times greater density of locations than bin *i*.

Buffer – A user-defined area around the perimeter of the user-defined area(s) of interest. We included the option to include a buffer for those users who want to evaluate the area surrounding a project site. The DST allows for a flexible buffer size so that users with different requirements have greater flexibility.

Composition – Refers to the quality of Golden Eagle habitat (based on SOS classes; see below) within the focal area, according to the four life history models (breeding, non-breeding, fall migration, and spring migration). Composition values, therefore, refer to relative density of Golden Eagle nesting areas, and relative intensity of use by Golden Eagles during the non-breeding season, spring migration, or fall migration, respectively.

Conservation priority – Conservation rank *after* considering current land protection status.

Conservation rank – Conservation rank indicates the importance of a focal area for Golden Eagles in comparison to a user-selected reference area. Conservation rank is therefore scale-specific and life-history-model-specific, and it does not take into account current land protection status. Conservation rank is found by comparing the mean conservation value of the focal area to the mean conservation values of other similar-sized areas within the reference area. For example, a conservation rank of 85 means that the focal area has greater mean conservation

value than 85% of similar-sized areas within the reference area. Conservation rank is estimated by ranking the mean Area Adjusted Frequency (AAF) (derived from the Zonation-transformed AAF surface) created for each life history model. It is estimated separately for each life history model by contextualizing the user-defined focal area relative to a large number of similar-sized polygons within the reference area (default is all of Wyoming). Conservation rank is estimated by placing the mean conservation value of your area(s) of interest into a frequency distribution of similar-sized areas within your reference area. Then, the proportion of similar-sized areas that have higher/lower mean conservation value to Golden Eagles is estimated. Hence, a conservation rank of 10 for the nesting model means that, on average, the focal area is estimated to have better nesting habitat than only 10% of similar-sized areas in Wyoming. In contrast, a conservation value of 95 for the nesting model means that, on average, the focal area has better nesting habitat than 95% of similar-sized areas in Wyoming (i.e., only 5% of similar-sized areas have better nesting habitat).

Conservation value – Refers to the ranked importance of all pixels in Wyoming for Golden Eagles.

Context Dependence – Refers to how the user-defined focal area is compared to similar-sized areas in Wyoming, and any other user-defined reference area within Wyoming. Hence, "lowest value" or "highest value" are relative to other areas, and the conservation values are different depending on the reference area. The default and broadest reference area is all of Wyoming, but the context would change if, for example, a comparison were made to the western US, or to a specific county within Wyoming.

Fall migration model – A model developed using Golden Eagle telemetry locations during their southward fall migration. Only locations from Golden Eagles originating outside of Wyoming were included in this model. The relative density for the fall migration model refers to the relative density of Golden Eagle migration locations (based on telemetry data), not the density of eagles.

Focal Area – User-defined polygon(s) for which Golden Eagle habitat will be analyzed. The composition, or relative density of use by Golden Eagles according to each life history model), will be calculated for the focal area, as will the conservation rank of the focal relative to the reference area.

Hazard – An anthropogenic feature on the landscape that increases mortality and/or decreases reproductive success of Golden Eagles that are exposed to it. Hazards can be chemical, biological, physical, cultural, or some combination.

MaxEnt – MaxEnt is an ecological niche model developed by Phillips et al. (2006). It is a presence-only model that compares presence locations of a focal species to a sample of "background" locations within the study area. For our models, we used 100,000 background locations.

Mitigation – Specific conservation actions or measures to avoid, minimize, or compensate for impacts to environmental resources.

Modeling Area – The area in which the MaxEnt models were created. For the models, we buffered Golden Eagle locations by 20 km for the nesting and non-nesting models, and by 50 km for the migration models. The modeling area was defined as the union of the circles defined by those buffered locations. It was within the modeling area that a random distribution of background locations (see MaxEnt) was distributed.

Modeling Region – The modeling region includes all of Wyoming and a buffer around Wyoming's perimeter. The modeling region is the additional geographic area beyond the modeling area that the MaxEnt model was projected into, which varied in size depending on the buffer applied to Golden Eagle locations.

Nesting model – Model created using known nest sites of Golden Eagles. We thinned nest site locations such that no locations were closer than 3 km (1.5 km radius) from each other (reducing the chance of including multiple nests within the same territory). The relative density for the nesting area model refers to the relative density of Golden Eagle nesting areas.

Non-nesting model – Model created using daytime locations of Golden Eagles during winter. We did not include locations within 2-km of breeding areas because we reasoned that such areas were already represented in the nesting model. We thinned locations such that no eagle had more than two locations per day (one morning, one afternoon - see Wallace et al. in review). We subsequently evaluated the model's ability to accurately predict adult, non-adult, migratory, and resident Golden Eagle winter locations. We also evaluated the model's ability to predict night-time roosts, and non-winter locations of non-breeding Golden eagles. In all such cases, the model provided good-to-excellent predictions. Hence, what was initially developed as a "winter" model is now considered a non-nesting model. Relative density for the non-nesting model represents the density of Golden Eagle telemetry locations, not the density of eagles per-se. It also can be interpreted as intensity of habitat use.

Reference Area – A user-selected area to which the focal area is compared (ie. for estimating relative conservation rank). If no reference area is selected, the default is all of Wyoming.

Relative Density – MaxEnt is equivalent to a point process model, and therefore represents the density of locations within environmental and geographic space. Absolute abundance is unknown, but the relative density of locations is modeled. If using the standard output from MaxEnt, relative density occurs along a gradient, but the magnitude of difference among different areas is unknown. If the standard output from MaxEnt is converted into AAF, relative density becomes a state variable with a known difference the magnitude of difference between/among different areas. Although absolute density is unknown, being able to estimate that one area has 3, 5, or 10 times higher relative density than another area is extremely valuable for conservation planning. For our nesting area model, relative density represents the relative density of Golden Eagle nesting areas. For the non-nesting, fall migration, and spring migration models, relative density represents the relative density of use (or intensity of use) (based on Golden Eagle telemetry locations), not the density of individuals.

Risk – Risk integrates relative density of Golden Eagles with the distribution/density of hazard(s). Risk to eagles may be low in areas with high hazard and low relative density of

eagles. Risk is greatest in areas with high hazard and high relative density of eagles (see Bedrosian et al. 2020 for an example).

Scale Dependence – Refers to how the user-defined focal area is compared to a large sample of similar-sized areas. A "high" conservation rank area should be interpreted only as high relative to similar-sized sample polygons within the reference area.

Species of greatest conservation need – A Wyoming-level designation intended to identify species whose conservation status warrants increased management attention, and funding, as well as consideration in conservation, land use, and development planning in Wyoming. SGCN designation can be derived from known population or habitat threats or a lack of sufficient information to adequately assess a species' status." (Wyoming Game and Fish Department. 2017. Wyoming Species of Greatest Conservation Need. Wyoming State Wildlife Action Plan, Introduction. 19 pp).

Spring migration model – A model developed using Golden Eagle locations during their northward spring migration. Only locations from Golden Eagles originating outside of Wyoming were included in this model. The relative density for the fall migration model refers to the relative density of Golden Eagle migration locations (based on telemetry data), not the density of eagles.

Strength of Selection (SOS) – SOS classes are derived from AAF-transformed Relative Density (Maxent's relative density made spatial by comparison with proportion of modeling area). SOS, therefore, has an identical meaning as AAF, but it is presented in a way that allows for symmetry in both positive and negative directions, around the neutral point of 1.0. For AAF values ≥ 1.0, SOS = AAF. For AAF <1.0, SOS = -1/AAF. For AAF, values <1.0 represent places where the proportion of locations is less than the proportion of area in the bin; and such areas are constrained to be between >0 and <1.0. However, for AAF ≥ 1.0, there is no upper constraint. Converting AAF to SOS simply makes interpretation (and visualization) much more intuitive. For example, an AAF = 0.2 and an AAF = 5 are the same magnitude of difference from 1.0 (1/5th the density and five-times the density). When converted to SOS, the values become -5.0 and 5.0, respectively - and are therefore much easier to interpret as identical magnitudes, in opposite directions.

Wyoming Golden Eagle Decision Support Tool – A digital support tool (DST) to facilitate decision-making related to Golden Eagle habitat across Wyoming. This DST spatially prioritizes Wyoming for golden eagles and is based on recently completed comprehensive models of relative habitat suitability across Wyoming for nesting, non-nesting, and fall and spring migration seasons. The DST provides an accessible online platform from which land management agencies, industry, NGOs, and others interested in Golden Eagle conservation can evaluate the relative importance of areas in Wyoming for golden eagle populations. Thus, the tool can be used to guide conservation actions aimed at avoiding, minimizing, or mitigating threats to eagles, as well as habitat conservation (e.g., land- use planning, easements, restoration), thereby improving the efficacy of such actions. Users can upload or draw areas of interest, and the DST produces summary statistics related to the relative density distribution of

eagles (by and across seasons) within that area. The tool also allows users to evaluate the area(s) of interest relative to similar sized parcels, multiple specific project areas (eg. alternative project areas), particular administrative units (eg. county, BLM Field Office, USFS District), surface management categories (eg. private, federal, state, tribal, conservation easement lands), or ecoregions. Finally, the tool provides additional overlays that can be incorporated into assessments, including and multi-species values (i.e.,. Greater Sage-grouse core areas, species richness maps for Wyoming Species of Greatest Conservation Need).

Zonation – Zonation is an open-source conservation planning algorithm that has the flexibility to integrate spatial data on multiple species, varying land ownership patterns (and priorities), and costs. See Moilanen ant Kujala (2008) for details.

Zonation-transformed AAF – AAF values smoothed and prioritized based on a ranking algorithm.

Frequently Asked Questions:

What is the difference between composition and conservation rank?

Composition and conservation rank are two different approaches used in the DST to evaluate Golden Eagle habitat values. Composition refers to a direct quantification of model values within the user-defined focal area (and buffer, if applicable), answering the question "What is the amount and distribution of habitat values (relative density of eagle locations or nest areas) in my area of interest?" While based on the same underlying models, conservation rank differs in that it provides a comparison of model values within the focal area to similarly sized areas in Wyoming or some other user-defined reference area. This answers the question "How important is my area of interest in comparison with other areas?"

What spatial scales is the DST designed to work at?

The DST provides estimates of conservation rank and composition of user-defined areas ranging from 100 ha to 100,000 ha. All models work extremely well at scales up to the entire state of Wyoming, but we do not provide conservation rank estimates for areas larger than 100,000 ha because there is not a large enough sample of similar-sized areas with which to compare them. At the smallest scales (e.g., hundreds of ha) we would encourage users to buffer their areas of interest, in order to represent the scales at which eagles use the landscape (e.g., a project happening within a 100-ha area might influence eagles within several kilometers of that area).

Are there spatial scales that are too big or too small for it to work at?

If users are focused on a single, very small focal area (e.g., one area that is from 10 ha to 100 ha), the DST will provide estimates, but the models' predictions work best at larger scales (>1,000 ha). The models perform extremely well at very large scales (e.g., subregions and ecoregions; see Wallace et al. in prep.) up to the statewide scale for predicting the distribution of eagles during different life history stages.

Do the models represent actual Golden Eagle densities?

No, relative density (intensity of use) should not be interpreted as equivalent to density of individual Golden Eagles. We created models of Golden Eagle nesting area relative density of use, non-breeding season intensity of use, fall migration intensity of use, and spring migration intensity of use. Nesting area density estimates relative density of individual nesting areas (territories), not total nests (several of which can occur within a single territory). Non-breeding season intensity of use refers to daytime use locations during the non-breeding season, and excludes those locations that occur within breeding territories (regardless of when they are used). Similarly, for both fall and spring migration models, we modeled the density of daytime locations used during migration, not the density of individual eagles.

Does a low score for conservation rank (or low AAF or SOS) mean that the area in question is unimportant for Golden Eagles?

No, a low conservation rank, AAF, or SOS value does not mean that the area is unimportant for Golden Eagles. These metrics represent areas along a gradient of densities, or intensities of use. For example, a focal area could have a low conservation rank, AAF, or SOS for nesting. This means that the predicted density of nesting areas is low in such an area. However, even low density areas have nesting sites/territories within them. These areas are still important for eagles, it just means there are relatively fewer nesting areas within that focal area. Such areas, owing to their rarity, could be even more important than "single nest sites" in high-density areas. Areas with high conservation rank, AAF, or SOS are areas with high relative intensity of use by Golden Eagles. Therefore, conservation actions in these areas could be more efficient and impactful because it encompasses higher relative densities of eagles. Likewise, if hazards are introduced in high conservation rank areas, this could result in higher risk to Golden Eagles simply due to the increased overlap between the hazard and higher relative densities.

What if there is a contradiction between on-the-ground data (e.g., locations of nest sites) and the DST's model predictions?

The DST models and prioritizes Golden Eagle habitat at broad spatial scales and is designed to complement on-the-ground Golden Eagle data. DST can help users prioritize areas based on Golden Eagle habitat, but is not intended to replace site-specific, on-the-ground surveys, which will always be preferable to model predictions.

What are some example applications of the DST?

This Decision Support Tool (DST) was developed to be of use and application to a wide variety of user groups, ranging from planners (e.g., of energy or recreation facilities, or for conservation) to NGOs to land management and regulatory agencies. We also developed it to be valuable to users of varying levels of experience (no experience to those with expertise) with ecological modeling, Golden Eagles, and conservation planning. The DST was developed to: 1) assist with project siting; 2) evaluate individual projects and/or comparing alternative projects; and 3) assist with identifying appropriate mitigation areas. The DST also can be used to conduct research (e.g., Use the DST to identify the "30 by 30" goals for Golden Eagles in Wyoming; assess overlap between high conservation value Golden Eagle habitat and Greater Sage-grouse Core Areas; or calculate the difference in mitigation value of locating power pole retrofits in varying locations).)

How can the DST strengthen Project Siting?

The DST can assist project siting by helping planners identify areas on the landscape along a gradient of value (and therefore risk) to Golden Eagles. Risk represents the combination of eagle density and some anthropogenic hazard that could represent additive eagle mortality (e.g., wind development, recreational development). Bedrosian et al. (2020) showed, empirically, that overlaying nest density models with power pole density models accurately predicted risk of Golden Eagle electrocution (i.e., the risk model accurately predicted the spatial distribution of >87% of 342 electrocutions in the study area). By evaluating an area's relative density of Golden Eagles, the DST can help site projects in areas of lower risk. Similarly, conservation planners

may wish to identify areas of high conservation value, or areas of increased potential for risk to Golden Eagles if conservation actions are not taken. The DST can identify high value areas for Golden Eagles for investment in conservation easements. Likewise, it can compare multiple potential investment properties based on their conservation ranks for Golden Eagles.

How can the DST be used to evaluate individual projects and/or compare alternative projects?

The DST can be used to evaluate individual projects or a series of alternative projects. Users can upload shape files and/or draw their own polygons, and have the area(s) selected evaluated for their: 1) nesting area value, 2) non-nesting value, 3) fall migration value, and 4) spring migration value. The distribution of each of these four life-history model values will be displayed for the selected area(s) and compared to a large sample of similar-sized areas within Wyoming as a whole. Hence, for a selected polygon, the user will have estimates of the value of that area to eagles during different life-history stages, in addition to contextualizing the relative value of the focal polygon, to all other areas of Wyoming. Multiple alternative project locations can also be compared to each other, in terms of the value of each area to Golden Eagles.

How can the DST assist with identifying appropriate mitigation areas?

By identifying the areas with the highest relative density of Golden Eagles, the DST can help users determine areas where mitigation actions may have the most impact. Mitigation involves conservation actions whose aim is to avoid, minimize, or compensate for impacts to environmental resources. Mitigation actions that target Golden Eagles will have the greatest impact in areas that contain the highest densities of eagles. Although mitigation actions taken within areas of low Golden Eagle densities still have an impact, it will not be as far-reaching as actions taken within higher conservation rank areas.

How much greater are estimated densities in the highest and high density areas than in the lowest density areas?

For all four models, high and highest density categories are quite rare in Wyoming. For example, for the nesting, non-nesting, fall migration, and spring migration models, only 3.52%, 2.36%, 0.952%, and 3.45% of Wyoming is estimated to exist in the highest density category, respectively. Those highest density areas are estimated to have much greater densities of nests/intensities of use than the lowest density areas, with the magnitudes of difference ranging from 36 times greater (for the fall migration model) to 75 times greater (for the nesting model). Similarly, high density areas are estimated to represent 4.56%, 9.60%, 5.26%, and 5.08% of Wyoming among the nesting, non-nesting, spring migration, and fall migration models, respectively. These high density areas are also estimated to have much greater densities/intensities of use than the lowest density areas, with magnitudes ranging from 18.15 times greater (for the fall migration model) to 29.65 times greater (for the nesting model) (see supplementary Modeling Summary document for additional details).

Why is my workflow not saved within the DST?

We ensure data privacy for everyone who uses this tool. No spatial data uploaded or created on the DST are stored on any servers, shared, or otherwise distributed. User data are not collected and users remain anonymous. No copies of reports, either created or downloaded, are maintained on the server. As a result of this data privacy policy, the DST does not save workflows.