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Research Article

Predicting Eagle Fatalities at Wind Facilities

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ABSTRACT The United States Fish and Wildlife Service (USFWS) recommends using a Bayesian modeling framework to predict the annual golden eagle (*Aquila chrysaetos*) fatality rate at a wind energy facility, and the modeling approach defines prior distributions for collision rate and exposure rate from data at existing wind projects. Collision rate is defined as the number of collisions per exposure. Exposure rate is a function of minutes of eagle activity and survey effort; we used site-specific data to update the prior distribution, resulting in the posterior distribution. An expansion factor adjusts the fatality prediction by accounting for daylight hours and the hazardous area within a wind project footprint. The product of the collision rate, posterior exposure rate, and expansion factor is the predicted annual fatality rate. We reviewed the input data for the prior distribution for collision rate, and provided an updated prior distribution for collision rate using more contemporary information. As suggested by the current USFWS guidance, we updated the prior distribution for collision rate from the USFWS baseline model with data from a site with modern specifications to obtain an updated prior distribution. We also created alternative prior distributions by estimating parameters for the distributions from data at 26 modern facilities only. Using more recent data and a larger data set, we determined the predictions using the alternative prior distributions for collision rate are approximately half the estimates using the original distribution.

KEY WORDS *Aquila chrysaetos*, Bayesian, collision, fatality prediction, golden eagles, USFWS Eagle Conservation Plan Guidance, wind energy.

Statistical models in the Bayesian framework use existing information about model parameters to develop prior probability distributions, and as more data become available prior distributions can be updated. The United States Fish and Wildlife Service (USFWS) developed a statistical collision risk model (CRM) in the Bayesian framework using observational data of golden eagles (*Aquila chrysaetos*). The USFWS Eagle Conservation Plan Guidance published prior distributions for the CRM as a baseline and suggests that other candidate models should be developed and compared to the baseline model. The USFWS states that a major goal of the modeling process is to reduce uncertainty by including new information into an adaptive modeling framework (USFWS 2013; Appendix A).

A formal policy of adaptive management has been adopted by the USFWS (Walters 1986), in which key uncertainties regarding the impact on golden eagles by wind facilities are to be minimized through a sequential process of model development, model testing and comparison, accumulation of updated information, and new data, followed by model rebuilding and renewed model testing. New et al. (2015) recently published an update to the prior probability distribution for exposure rate to be used in the CRM, demonstrating a pathway for providing updates so that the information is available to managers, statisticians, and scientists.

The baseline prior probability distribution for the collision rate in the CRM was developed with data from 4 wind farms, most with outdated turbine types. Given the numerous studies of raptors and eagles at wind farms and new turbine technology, an update to the prior probability distribution for the collision rate is warranted. Our intent was to update the data used to inform the prior probability distribution for the collision rate within the CRM.

STUDY AREA

We reviewed and obtained data from publicly available studies that were collected from 1994 to 2013 at 40 wind-energy facilities across North America with modern turbine specifications. Fifteen of the 40 wind-energy facilities were located east of the Mississippi River in Illinois, Maine, New Hampshire, New York, Oklahoma, South Dakota, West Virginia, and Wisconsin, USA and Ontario, Canada. Twenty-five facilities were located west of the Mississippi River in Arizona, California, Oregon, Washington, and Wyoming, USA. The habitats at these wind energy facilities

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varied widely from forested ridgetops, to shrub–scrub habitat, to agricultural fields and grasslands. The climactic conditions, native species, and ecological communities also varied substantially because the facilities were constructed across North America within differing biomes at widely dispersed locations and at varying elevations.

METHODS

Collision Risk Model Parameters

The Eagle Conservation Plan Guidance (USFWS 2013: appendix D [table D-1]) and New et al. (2015) modeled annual eagle fatalities (F) caused by collisions with wind turbines using a CRM as:

$$F = \varepsilon \times \lambda \times C,$$

where ε is an expansion factor that scales the fatality rate based on the size of the project to the annual predicted fatalities for the project, λ is the rate of eagle exposure to turbine hazards, and the collision rate (C) is the rate that eagle exposure results in a collision with a turbine. The CRM is a combination of 2 separate distributions: the distribution for the collision rate and the distribution for exposure rate, and a constant associated with facility characteristics (i.e., the expansion factor).

Collision rate.—The collision rate is the rate of an eagle having a fatal collision with a turbine given exposure in the hazardous area, which is defined as the 3-dimensional space around the rotor swept area. The hazardous area is a cylinder centered at the base of a turbine. The radius of the cylinder is equal to the rotor-swept radius of the turbine and the height of the cylinder is equal to height of the turbine blade.

The prior distribution for collision rate was estimated from Whitfield (2009), who used a 2-stage Band CRM (Band et al. 2007) to estimate eagle avoidance rate. Whitfield (2009) estimated avoidance as the inverse of the probability of collision (1—probability of collision), where the rate of collision was estimated as fatalities per exposures, assuming no avoidance. The prior distribution for collision rate is a Beta distribution and is given as:

$$C_{\text{prior}} \sim \text{Beta}\ (v, v'),$$

where v and v' represent the shape and rate parameters for the Beta distribution and the resulting distribution is meant to represent the possible collision rates for any project considered; v represents the number of collisions and v' represents the amount of exposures that did not result in collisions.

Exposure rate.—Exposure rate (λ) is the expected number of exposure events (i.e., eagle min/(hr $\times$ km^3); New et al. 2015) across the facility. The USFWS recommends estimating exposure events using the number of minutes eagles are observed during survey times within 800 m of point count locations and flying no higher than 200 m, assuming high detection rate within this area (USFWS 2013). The survey effort (hr $\times$ km^3) is quantified as the number of hours of surveys at a point count location where the survey area is a cylinder area, centered at the point count locations as described above. The prior distribution for exposure rate is a Gamma distribution and is defined as:

$$\lambda_{\text{prior}} \sim \text{Gamma}\ (\alpha, \beta),$$

where α and β represent the shape and rate parameters for the Gamma distribution and the resulting distribution represents the possible exposure rates for any project considered; α represents the number of eagle minutes and β represents survey effort in hours $\times$ km^3.

The prior distribution is intended as a starting point to estimate exposure rates for any wind energy facility regardless of the expected exposure rate at that facility (i.e., assumes equal exposure rates).

The USFWS recommends using exposure data for eagles collected during pre-construction surveys for a particular wind facility to update the prior distribution to estimate the parameters for the posterior distribution (USFWS 2013). By assuming that number of minutes of exposure follows a Poisson distribution, the posterior distribution for exposure rate is:

$$\lambda_{\text{posterior}} \sim \text{Gamma}\ \left(\alpha + \sum_{i=1}^{n} k_i, \beta + n\right),$$

where $\sum k_i$ is the number of observed minutes eagles were exposed, n is the number of survey hours $\times$ km^3 in the pre-construction survey, and α and β are from the prior distribution.

Expansion factor.—The expansion factor (ε) is used to scale the fatality rate (fatalities/(hr $\times$ km^3)) for the facility to the daylight or operational hours (τ) in time period and total hazardous area (km^3) within the wind energy facility of interest. The fatality rate is the product of the prior distribution for collision rate and the posterior distribution for exposure rate. The expansion factor is:

$$\varepsilon = \tau \sum_{i=1}^{n} \delta_i\,,$$

where n is the number of turbines and δ is the 3-dimensional hazardous area centered at the base of a turbine (described above in the collision rate section).

Predicted annual fatalities.—The distribution of predicted annual fatalities can be estimated as the product of the expansion factor, the posterior exposure rate, and the prior probability distribution for the collision rate:

$$F = \varepsilon \times \lambda_{\text{posterior}} \times C_{\text{prior}}\,.$$

We used the distribution of estimated annual fatalities to obtain statistics such as predictions for the mean, standard deviation, and 80th credible interval (CRI) of annual fatalities as recommended by the USFWS in the Eagle Conservation Plan Guidance (USFWS 2013). A CRI in the Bayesian framework is analogous to a confidence interval in frequentist statistics.

Estimating the Prior Distribution for Collison Rate

To estimate the prior distribution for collision rate, we estimated the number of golden eagle fatalities and exposures during post-construction monitoring for each facility in the data set. We estimated the collision rate as fatalities per collisions without avoidance. We estimated the number of fatalities using the Smallwood (2007) bias correction factor that adjusts for the probability that a carcass was available to be found and detected by a searcher. We used Whitfield (2009) to estimate the collisions without avoidance.

We estimated the average collision rate for the prior distribution by summing the fatalities per study period for all facilities and dividing by the sum of the collisions without avoidance per study period for all facilities. We estimated the variance using bootstrapping (Manly 1997). We estimated the parameters for the prior distribution for collision rate using a method of moments approach assuming that the prior distribution for collision rate followed a Beta distribution.

Wind Energy Facility Abundance and Mortality Data

We reviewed publicly available data from wind energy facilities that reported results of point-count surveys and fatality monitoring to update the prior distribution for collision rate. We verified that robust methods for both the point count and fatality monitoring surveys were implemented; we have >20 years of experience working with both the agencies and industry in the development of standardized methods. Additionally, we included data only from facilities with turbines greater than 500 kW because outdated wind turbine technology has different collision risk than modern turbines (Leslie et al. 2012).

We reported golden eagle use (observations/plot/survey hr) and number of golden eagle fatalities in publicly available wind-energy reports from 40 facilities (Appendices A–C; see also Table S1, available online at www.onlinelibrary.wiley.com). We used data from 26 facilities with publicly available wind-energy reports in our analysis where golden eagle observations were made during fixed-point surveys (Table 1). There were 14 projects where golden eagle observations were not observed during fixed-point surveys (see Table S1, available online at www.onlinelibrary.wiley.com); these projects were not included in this analysis.

We estimated a prior distribution for collision rate from data collected at the 26 facilities with modern specifications. To estimate the number of fatalities that occurred at the facilities during post-construction monitoring, we included fatalities found during scheduled carcass searches and incidental fatalities (i.e., fatalities found at turbines that were not monitored) if it was believed that the fatality was

Table 1. Mean golden eagle use (observations/800-m plot/20-min survey) and number of golden eagle fatalities at the 26 facilities with publicly available wind energy reports (known in 2013) that had eagle use and number of fatalities collected. Golden eagle data were collected from 1994 to 2013 at 26 wind facilities in the United States with modern turbine specifications.

Project (state)	$\bar{x}$ use[a]	Survey hr[b]	No. fatalities[c]	Study length (months)[d]
Alta Oak Creek Mojave: Alta I (CA)	0.020	110.0	0	0
Alta Oak Creek Mojave: Alta II–V (CA)	0.007	88.0	0	2
Campbell Hills (WY)	0.360	135.0	0 (1 incidental)	12
Combine Hills (OR)	0.031	113.5	1	24
Diablo Winds (CA)	0.268	80.0	1 (1 incidental)	24
Dry Lake (AZ)	0.016	139.5	0	0
Elkhorn (OR)	0.270	91.7	2	24
Foote Creek Rim Phase I (WY)	0.265	1,290.0	0	36
Foote Creek Rim Phases II and III (WY)	0.265	1,290.0	1	18
High Winds (CA)	0.297	329.0	1 (1 incidental)	24
Hopkins Ridge (WA)	0.007	126.0	0	24
Kittitas Valley (WA)	0.026	96.0	0	0
Klondike (OR)	0.003	26.0	0	12
Leaning Juniper (OR)	0.024	97.7	0	24
Nine Canyon (WA)	0.003	99.5	0	12
Shiloh I (CA)	0.051	103.5	1	36
Shiloh II (CA)	0.019	103.5	0	12
Stateline (OR and WA)	0.020	122.7	0	30
Tuolumne (WA)	0.078	22.0	0	0
Vansycle (OR)	0.010	247.5	0	12
Vantage (WA)	0.010	94.4	0	0
Vasco (CA)	0.120	16.0	0	1
Wessington Springs (SD)	0.010	60.0	0	0
White Creek (WA)	0.004	86.7	0	0
Wild Horse (WA)	0.050	89.5	0	12
Windy Flats (WA)	0.010	94.7	0	0

[a] Annual average no. golden eagles/800-m plot/20-min survey.
[b] Effort, survey hours, for point surveys.
[c] Raw fatality count found during scheduled carcass searches (no. fatalities found incidentally) during study length.
[d] Length in years of post-construction monitoring.

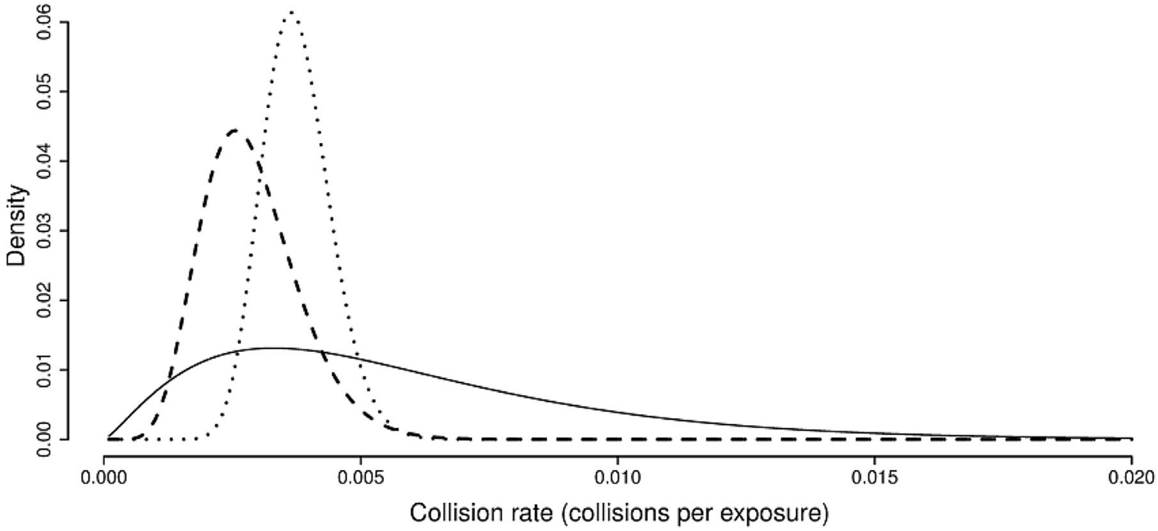

Figure 1. The updated modern facility collision rate priors for golden eagles at wind farms are Beta (9.28, 3,224.51) distribution with a mean of 0.0029 and a standard deviation of 0.0009 for the modern collision prior (dashed line) and a Beta (32.56, 8,641.52) with a mean of 0.0038 and a standard deviation of 0.0007 for the updated United States Fish and Wildlife Service (USFWS) collision prior (dotted line). Also presented is the USFWS prior (solid line). Data collected from 1994 to 2013 from the following wind projects: Dry Lake I–II, Arizona; Alta Oak Creek Mojave (Alta I–V), Diablo Winds, High Winds, Shiloh I–II, and Vasco, California; Combine Hills, Elkhorn, Klondike, Leaning Juniper, and Vansycle, Oregon; Stateline, Oregon and Washington; Wessington Springs, South Dakota; Hopkins Ridge, Kittitas Valley, Nine Canyon, Tuolumne, Vantage, White Creek, Wild Horse, and Windy Flats, Washington; and Campbell Hills and Foote Creek Rim (Phases I–III), Wyoming, USA.

caused by the wind facility when scheduled carcass searches were taking place (Table 1). We did not adjust incidental fatalities for the probability that a carcass was available and detected. We adjusted fatalities found during a scheduled carcass search by a project-specific probability of a carcass being available and detected using the Smallwood (2007) bias correction factors. We used large birds (e.g., mallards [*Anas platyrhynchos*], rock pigeons [*Columba livia*]) as a surrogate for golden eagles to estimate the searcher efficiency rate, consistent with Whitfield (2009). We used values and estimates to calculate the collisions per annum without avoidance and we calculated adjusted fatalities per facility (Appendices A and B, respectively). Additionally, we estimated a prior distribution for collision rate using the data from the 26 facilities with modern specifications and the 3 additional facilities with old-generation wind turbines that we included in the prior distribution for collision rate presented in the Eagle Conservation Plan Guidance (USFWS 2013). The Foote Creek Rim facility was the only modern wind facility used in prior distribution for collision rate presented in the Eagle Conservation Plan Guidance and we included it as 1 of the 26 modern wind facilities in the updated data set.

We assume that the proper protocol for animal use and care was followed for all data collection. In addition, we have an established procedure of minimizing wildlife disturbance during surveys because we attempt to minimize the influence of our personnel on wildlife to ensure the quality of data collected. We developed data collection methods that have served as the foundation of voluntary guidelines developed by the USFWS and used by the industry, and our principle scientists have been on advisory committees for developing standards of data collection at wind projects (Anderson et al. 1997, 1999; Johnson et al. 2000*a* as cited by USFWS [2003]; Strickland et al. 2011 as cited by USFWS [2012, 2013]).

Model Validation

We used leave-one-out cross-validation (LOOCV; Allen 1974) to determine how accurately the CRM should perform in practice. We compared the model predictions using the various prior distributions for collision rate to the estimated fatality rates from post-construction monitoring, corrected for the probability that the carcass is available and detected for all facilities (i.e., with the goal of determining how well the model fits the data).

To evaluate the performance of the CRM, an independent estimate of annual fatality rate for wind facility i is obtained

Table 2. Goodness-of-fit statistics for fatality prediction of golden eagles from the modern collision prior, updated United States Fish and Wildlife Service (USFWS) prior, and the original USFWS prior from golden eagle data collected from 1994 to 2013 at the following 26 wind facilities with modern turbine specifications: Dry Lake I–II, Arizona; Alta Oak Creek Mojave (Alta I–V), Diablo Winds, High Winds, Shiloh I–II, and Vasco, California; Combine Hills, Elkhorn, Klondike, Leaning Juniper, and Vansycle, Oregon; Stateline, Oregon and Washington; Wessington Springs, South Dakota; Hopkins Ridge, Kittitas Valley, Nine Canyon, Tuolumne, Vantage, White Creek, Wild Horse, and Windy Flats, Washington; and Campbell Hills and Foote Creek Rim (Phases I–III), Wyoming, USA.

Measure of goodness of fit	Modern collision prior	Updated USFWS prior	Original USFWS prior
$\bar{x}$ deviation ($\bar{x}$−annual fatality rate)	0.03	0.16	0.46
$\bar{x}$ absolute deviation	0.44	0.50	0.74
Root mean squared prediction error	0.63	0.71	1.06

by omitting the i^{th} wind facility from the data set and estimating the parameters for the prior distribution for collision rate using the methods described above from the remaining $n-1$ facility data, where n is the total number of wind facilities. The modified prior probability distribution for the collision rate is used to predict annual fatalities for the i^{th} observation. This process is repeated n times to obtain a fatality estimate for each wind facility.

We considered the deviation between the average fatality prediction and the estimated number of eagle fatalities from post-construction monitoring (DEV), the absolute value of DEV, and the root mean squared prediction error (RMSPE) as goodness-of-fit metrics to evaluate the fit of 3 models.

The RMSPE is the square root of the average of the squared DEV values:

$$\sqrt{\left[\sum_{i=1}^{n}\left(e_i - \hat{e}_i\right)^2\right]/n},$$

where e_i is the estimated number of eagle fatalities from post-construction monitoring adjusted for the probability of available and detected and $\hat{e}_i$ is the predicted annual fatalities from the model being tested at wind facility i.

RESULTS

We estimated a prior distribution for collision rate using data from the 26 sites with modern specifications. The mean and standard deviation of the estimated collision rate for the modern collision prior were 0.0029 and 0.0009, respectively. The prior probability distribution for the collision rate for the modern collision prior is given as:

$$C_{\text{modern prior}} \sim \text{Beta}\,(v, v'),$$

with parameters $v = 9.28$ and $v' = 3{,}224.51$ (Fig. 1).

To allow more flexibility in the model, we estimated a prior distribution for collision rate using data from the 26 sites

Table 3. Model prediction priors and goodness-of-fit statistics using the modern collision prior, the original United States Fish and Wildlife Service (USFWS) prior, and the updated USFWS prior estimated from golden eagle data collected from 1994 to 2013 at 26 wind facilities in the United States with modern turbine specifications. Model predictions were compared to an adjusted fatality estimate calculated using the Smallwood (2007) bias correction factor.

		Modern collision prior			Updated USFWS prior			Original USFWS prior		
Project (state)	**Smallwood (2007) fatality estimate**	**80% credible point**	$\bar{x}$	**Deviation $\bar{x}$−fatality estimate**	**80% credible point**	$\bar{x}$	**Deviation $\bar{x}$−fatality estimate**	**80% credible point**	$\bar{x}$	**Deviation $\bar{x}$−fatality estimate**
Alta Oak Creek Mojave: Alta I (CA)	0.00	0.29	0.21	0.21	0.36	0.27	0.27	0.61	0.41	0.41
Alta Oak Creek Mojave: Alta II–V (CA)	1.66	0.27	0.19	−1.47	0.39	0.27	−1.38	0.66	0.44	−1.22
Campbell Hills (WY)	1.00	2.98	2.36	1.36	3.30	2.87	1.87	6.21	4.23	3.23
Combine Hills (OR)	1.68	0.22	0.17	−1.52	0.31	0.24	−1.44	0.57	0.39	−1.29
Diablo Winds (CA)	1.21	0.32	0.25	−0.95	0.41	0.35	−0.86	0.80	0.54	−0.67
Dry Lake I (AZ)	0.00	0.08	0.06	0.06	0.11	0.08	0.08	0.19	0.13	0.13
Dry Lake II (AZ)	0.00	0.09	0.07	0.07	0.11	0.08	0.08	0.19	0.13	0.13
Elkhorn (OR)	2.07	1.96	1.52	−0.56	2.49	2.11	0.03	4.84	3.29	1.22
Foote Creek Rim; Phase I (WY)	0.00	0.67	0.54	0.54	0.73	0.65	0.65	1.41	0.96	0.96
Foote Creek Rim; Phases II and III (WY)	0.77	0.35	0.28	−0.50	0.41	0.36	−0.41	0.81	0.55	−0.22
High Winds (CA)	1.02	1.43	1.13	0.11	1.70	1.48	0.45	3.31	2.26	1.24
Hopkins Ridge (WA)	0.00	0.11	0.08	0.08	0.14	0.10	0.10	0.23	0.15	0.15
Kittitas Valley (WA)	0.00	0.22	0.16	0.16	0.27	0.21	0.21	0.48	0.32	0.32
Klondike (OR)	0.00	1.04	0.71	0.71	1.31	0.89	0.89	2.05	1.35	1.35
Leaning Juniper (OR)	0.00	0.22	0.16	0.16	0.27	0.21	0.21	0.47	0.32	0.32
Nine Canyon (WA)	0.00	0.02	0.01	0.01	0.02	0.02	0.02	0.04	0.02	0.02
Shiloh I (CA)	0.67	0.15	0.11	−0.56	0.19	0.15	−0.52	0.35	0.24	−0.43
Shiloh II (CA)	0.00	0.08	0.06	0.06	0.09	0.07	0.07	0.16	0.11	0.11
Stateline (OR and WA)	0.00	0.47	0.35	0.35	0.57	0.44	0.44	0.99	0.67	0.67
Tuolumne (WA)	0.00	0.99	0.72	0.72	1.22	0.91	0.91	2.06	1.38	1.38
Vansycle (OR)	0.00	0.02	0.01	0.01	0.02	0.02	0.02	0.04	0.03	0.03
Vantage (WA)	0.00	0.10	0.07	0.07	0.13	0.09	0.09	0.21	0.14	0.14
Vasco (CA)	1.00	2.42	1.76	0.76	3.02	2.28	1.28	5.16	3.46	2.46
Wessington Springs (SD)	0.00	0.07	0.05	0.05	0.08	0.06	0.06	0.14	0.09	0.09
White Creek (WA)	0.00	0.13	0.09	0.09	0.17	0.11	0.11	0.27	0.17	0.17
Wild Horse (WA)	0.00	0.83	0.64	0.64	1.00	0.80	0.80	1.8	1.22	1.22
Windy Flats (WA)	0.00	0.27	0.19	0.19	0.34	0.24	0.24	0.56	0.37	0.37

with modern specifications and the facilities from Whitfield (2009) with old generation turbines. The mean and standard deviation of the estimated collision rate for the updated USFWS collision prior were 0.0038 and 0.0007, respectively. The prior probability distribution for the collision rate for the combined collision prior is given as:

$$C_{\text{combined prior}} \sim \text{Beta}\ (v, v'),$$

with parameters $v = 32.56$ and $v' = 8{,}641.52$ (Fig. 1).

The objective of constructing prior distributions for collision and exposure rates is to obtain models for which predictions are realistic when compared to estimated number of eagle fatalities from post-construction monitoring. The DEV using Smallwood (2007) was 0.03, 0.16, and 0.46 for the modern collision, the updated USFWS prior, and the prior distribution for collision rate presented in the Eagle Conservation Plan Guidance, respectively (Table 2). All models are conservative and erred on the side of the resource, but the original USFWS prior was more conservative than the updated USFWS prior and the modern collision prior.

We illustrated the difference between the 80th CRI and the observed fatality rate for all 26 projects used to estimate the modern collision prior (Table 3, Fig. 2). The key difference between the predictions was that the magnitude of the deviations tended to be overly conservative for the original USFWS model. The RMSPE was 0.63 for the modern collision prior, which was smaller than the RMSPE for the original USFWS model of 1.06.

DISCUSSION

Our update of the prior probability distribution for the collision rate included data from modern wind facilities that were not available to the USFWS when the Eagle Conservation Plan Guidance Version 2 (USFWS 2013) was released and allows for a more accurate representation of proposed and recently built wind-energy facilities. In accordance with the USFWS model in the Bayesian framework, we have updated the prior probability distribution for the collision rate with a larger more consistent data set.

The USFWS model in the Bayesian framework is fairly simple, which should increase its application across the various stakeholders, and also increases its use as a tool in assessing potential impacts during the various stages of wind energy development and operations. However, this simplicity also creates the potential for more uncertainty regarding modeling results and potential impacts, especially when facilities have differences in the factors that influence risk compared to the facilities used to develop the model. Given this uncertainty, the USFWS recommends application of the model in the Bayesian framework in a manner that is conservative on the side of eagles. However, the current fatality predictions from the USFWS model could make permitting more challenging from a public perception standpoint during the public comment process (i.e., that the USFWS is authorizing an excessive amount of take) and from an analytic and legal authorization standpoint (i.e., can the population withstand the level of take). We conclude that the new prior probability distribution for the collision rate we calculated is more accurate and precise than the original prior distribution for predicting fatalities, and as a result will help address the aforementioned issues, while continuing to serve as an effective tool in estimating eagle collisions.

Additional modeling of pre- and post-construction data at wind energy facilities is needed to achieve better fatality predictions and should be ongoing. In addition, the current model in the Bayesian framework assumes that there is equal collision risk among sites when post-construction data are not available, an unlikely scenario. Including covariates in the

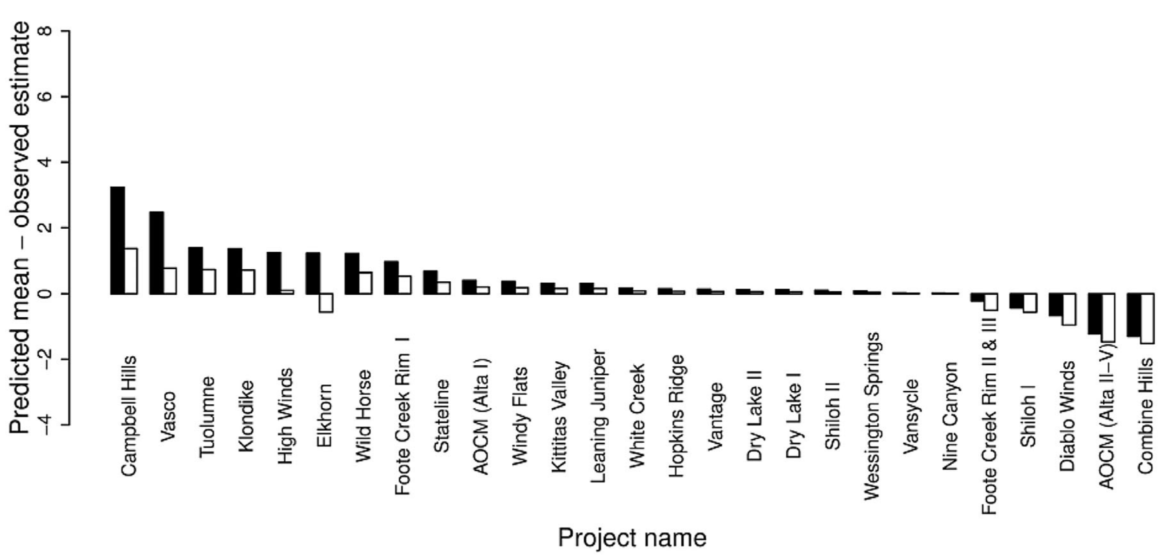

Figure 2. Comparison of the differences between the 80th CRI of the predictions and the observed data estimate from the modern collision prior (white) and the original United States Fish and Wildlife Service (USFWS) model (black) for estimating collisions of eagles with turbines at wind farms. Bars extending below the zero line indicate negative values (under-prediction). Golden eagle data were collected from 1994 to 2013 at 26 wind facilities in the United States with modern turbine specifications.

Beta, prior probability distribution for the collision rate would help reduce uncertainty in eagle CRM. Covariates such as topographic diversity, roughness, prominent wind direction, and other factors may improve the fit and precision of the models.

As is the case with all modeling efforts, the results are only as good as the data used to develop and apply the models. It is important to keep in mind the type of data used to develop the models including the type of turbine, study protocols, data collection methodologies, and the species that is being studied. Further uncertainty exists when the type of data used to apply the model differs from the data used to develop the model. We believe that a model developed and applied by using data collected under the same study protocols, the same data collection methodologies, for the same species (e.g., bald eagles [*Haliaeetus leucocephalus*] versus golden eagles), at the same type of wind energy facilities (those facilities for which we are trying to assess potential impacts) would further reduce the current uncertainty in eagle CRM results.

MANAGEMENT IMPLICATIONS

As a continued effort to reduce uncertainty in eagle CRM results is made through updating the USFWS model in the Bayesian framework, we make several recommendations. In accordance with the Bayesian framework, we suggest that managers use the 90th CRI of the CRM using the modern collision prior, given the less conservative predictions, for predicting impacts of new generation facilities. This deviates from the USFWS suggestion of the 80th CRI in the Eagle Conservation Plan Guidance (USFWS 2013) but still errs on the side of the resource (eagles). In addition, as the Eagle Conservation Plan Guidance suggests, continued investigation into other possible models for predicting golden eagle fatalities should be conducted. This could include a simple linear regression model using pre-construction eagle use (observations/plot/study period) data to predicted eagle fatality rates, more complex multiple regression models, or resource selection models using use data along with various landscape, temporal, and/or weather variables to help predict eagle fatality rates. Also, we recommend updating the prior distribution for collision rate with data that have been collected per the recommendations in the Eagle Conservation Plan Guidance (USFWS 2013) for the specific eagle species as they become available. We suggest that any updated prior distribution for collision rate be developed independently and in combination with the modern collision prior data set given the substantial suggested differences in data collection methods. We also suggest development of a process by which the data and reports associated with the pre- and post-construction surveys can be made readily available and the prior distributions can be updated in a streamline manner for real time application to inform management decisions.

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APPENDIX A

Values and estimates used in calculating the collision per annum with no avoidance using Whitfield (2009) estimated from golden eagle data collected from 1994 to 2013 at 26 wind facilities with modern turbine specifications in the United States. Out of the 26 modern wind facilities in the updated data set, only 2% of eagle flight minutes were >200 m. Therefore, we adjusted the number of eagle flight minutes for all projects by 98% for the proportion of flights <200 m. The percentage of perched locations is unknown, but we assumed that if an eagle is perched within 800 m, it would eventually fly and be at risk for collision. We assumed that each project was operational during 10 daylight hours on an average day (i.e., blades turning at speeds where eagles are active and therefore at risk of collision) because Whitfield (2009) assumed 10 hours of daylight operational time for Foote Creek Rim I. If the projects used to estimate the collision probability prior distribution were operational >10 daylight hours on average per day, the collision probability estimates are conservative (an overestimate).

Project, state	Plot area (ha)	Observation time (min)	Time bird spent in flight (min)	Flight risk area (ha)	No. of turbines	Rotor diameter	Rotation period (sec)	Collisions per annum[a] (no avoidance) for no. of turbines
Alta Oak Creek Mojave (Alta II–V), California	201.1	6,600.0	2.2	149.2	190	90.0	3.26	42.12
Alta Oak Creek Mojave (Alta I), California	201.1	5,280.0	5.3	78.5	100	77.0	3.26	56.75
Campbell Hills, Wyoming	201.1	8,098.2	147.2	51.8	66	77.0	2.94	720.35
Combine Hills, Oregon	201.1	6,810.0	10.4	81.7	104	61.4	3.03	75.20
Diablo Winds, California	201.1	4,800.0	64.2	24.3	31	47.0	2.11	183.44
Dry Lake I, Arizona[b]	201.1	8,370.0	6.7	23.6	30	88.0	3.45	15.20
Elkhorn, Oregon	201.1	5,500.0	74.3	47.9	61	82.0	4.17	444.83
Foote Creek Rim (Phase I), Wyoming	201.1	77,400.0	1,024.0	54.2	69	42.0	1.76	448.75
Foote Creek Rim (Phases II and III), Wyoming	201.1	77,400.0	1,024.0	28.3	36	42.0	1.76	234.13
High Winds, California	452.4	19,740.0	292.8	70.7	90	80.0	3.61	331.46
Hopkins Ridge, Washington	201.1	7,560.0	2.5	68.3	87	80.0	3.57	16.27
Kittitas Valley, Washington	201.1	5,580.0	7.3	37.7	48	88.0	3.53	38.75
Klondike, Oregon	201.1	1,560.0	1.5	190.1	242	80.0	2.94	140.71
Leaning Juniper, Oregon	201.1	5,860.0	7.0	52.6	67	77.0	2.94	48.26
Nine Canyon, Washington	201.1	5,970.0	0.8	29.1	37	62.0	3.16	2.31
Shiloh I, California	804.2	6,210.0	15.9	78.5	100	77.0	3.00	38.15
Shiloh II, California	804.2	6,210.0	6.0	58.9	75	94.0	4.00	11.29
Stateline, Oregon and Washington	201.1	7,360.0	7.4	356.6	454	47.0	2.11	200.86
Tuolumne, Washington	201.1	1,320.0	5.1	48.7	62	92.7	3.83	152.40
Vansycle, Oregon	201.1	14,850.0	7.5	29.8	38	47.0	2.11	8.49
Vantage, Washington	201.1	5,720.0	2.9	47.1	60	77.0	3.33	16.89
Vasco, California	78.5	960.0	5.8	26.7	34	108.0	3.75	393.69
Wessington Springs, South Dakota	201.1	3,600.0	1.8	26.7	34	77.0	3.33	9.56
White Creek, Washington	201.1	5,200.0	1.0	69.9	89	93.0	3.75	11.35
Wild Horse, Washington	201.1	5,370.0	13.4	99.7	127	78.0	3.57	174.27
Windy Flats, Washington	201.1	5,680.0	2.7	89.5	114	93.0	3.75	34.68

[a] Rotor depth, bird length, and flight speed are all taken from Whitfield (2009).
[b] Dry Lake II used the same pre-construction data as Dry Lake I.

APPENDIX B

Values and estimates used in calculating the adjusted fatality estimates using the Smallwood (2007) bias correction factor estimated from golden eagle data collected from 1994 to 2013 at 26 wind facilities in the United States with modern turbine specifications.

Project, state	Fatalities found during carcass searches	Incidentals	No. turbines searched	No. turbines at facility	Survey length (months)	Searcher efficiency	Search interval (days)
Alta-Oak Creek Mojave (Alta I), California	0	0	25.0	100	13	0.77	14
Alta-Oak Creek Mojave (Alta II–V), California	0	2	41.0	190	15	0.77	14
Campbell Hills, Wyoming	0	1	22.0	66	12	0.68	15
Combine Hills, Oregon	1	0	46.5	104	24	0.71	28
Diablo Winds, California	1	1	31.0	31	24	0.76	28
Dry Lake I, Arizona	0	0	15.0	30	14	0.91	10
Dry Lake II, Arizona	0	0	31.0	31	12	0.96	10
Elkhorn, Oregon	2	0	46.0	61	24	0.68	22
Foote Creek Rim (Phase I), Wyoming	0	0	69.0	69	36	0.93	28
Foote Creek Rim (Phases II and III), Wyoming	1	0	36.0	36	18	0.93	28
High Winds, California	1	1	90.0	90	24	1.00	15
Hopkins Ridge, Washington	0	0	43.0	87	24	0.75	22
Kittitas Valley, Washington	0	0	48.0	48	12	0.43	22
Klondike, Oregon	0	0	30.3	242	72	0.64	22
Leaning Juniper, Oregon	0	0	17.0	67	24	0.64	22
Nine Canyon, Washington	0	0	37.0	37	12	0.78	22
Shiloh I, California	1	0	50.0	100	36	1.00	7
Shiloh II, California	0	0	25.0	75	12	0.90	7
Stateline, Oregon and Washington	0	0	297.3	454	30	0.78	28
Tuolumne, Washington	0	0	21.0	62	12	0.64	22
Vansycle, Oregon	0	0	38.0	38	12	0.88	28
Vantage, Washington	0	0	30.0	60	12	0.52	30
Vasco, California	0	1	34.0	34	12	0.70	28
Wessington Springs, South Dakota	0	0	20.0	34	8	0.60	14
White Creek, Washington	0	0	89.0	89	48	0.44	14
Wild Horse, Washington	0	0	64.0	127	12	0.74	15
Windy Flats, Washington	0	0	36.0	114	12	0.58	30

APPENDIX C

Sources for the golden eagle data used for calculating the collision per annum with no avoidance using Whitfield (2009) and for the adjusted fatality estimates using the Smallwood (2007) bias correction factor. Golden eagle data were collected from 1994 to 2013 at 26 wind facilities in the United States with modern turbine specifications.

Project (state)	Fixed point (use) reference	Fatality reference
Alta Oak Creek Mojave: Alta I (CA)	Erickson and Chatfield (2009)	A. Chatfield, Western EcoSystems Technology, Inc., unpublished data
Alta Oak Creek Mojave: Alta II–V (CA)	Erickson and Chatfield (2009)	A. Chatfield, unpublished data
Campbell Hills (WY)	Taylor et al. (2008)	K. Taylor, Western EcoSystems Technology, Inc., unpublished data
Combine Hills (OR)	Young et al. (2003*c*)	Young et al. (2006); T. Enz, Western EcoSystems Technology, Inc., unpublished data
Diablo Winds (CA)	Western EcoSystems Technology, Inc. (2006); Western EcoSystems Technology, Inc., unpublished data	Western EcoSystems Technology, Inc. (2006); Western EcoSystems Technology, Inc., unpublished data
Dry Lake (AZ)	Young et al. (2007*b*)	Thompson and Bay (2012); J. Thompson, Western EcoSystems Technology, Inc., unpublished data
Elkhorn (OR)	Western EcoSystems Technology, Inc., unpublished data	T. Enk, Western EcoSystems Technology, Inc., unpublished data
Foote Creek Rim; Phase I (WY)	Johnson et al. (2000*b*)	Young et al. (2003*b*)
Foote Creek Rim; Phases II and III (WY)	Johnson et al. (2000*b*)	Young et al. (2003*d*)
High Winds (CA)	P. Kerlinger, Curry and Kerlinger Limited Liability Company, unpublished data	Kerlinger et al. (2006*a*)
Hopkins Ridge (WA)	Young et al. (2003*a*)	Young et al. (2007*a*)
Kittitas Valley (WA)	Erickson et al. (2003*b*)	Stantec Consulting Services, Incorporated, unpublished data
Klondike (OR)	Johnson et al. (2002)	Johnson et al. (2003)
Leaning Juniper (OR)	K. Kronner, Northwest Wildlife Consultants, Incorporated, unpublished data	R. Gritski, Northwest Wildlife Consultants, Incorporated, unpublished data
Nine Canyon (WA)	W. P. Erickson, Western EcoSystems Technology, Inc., unpublished data	Erickson et al. (2003*c*)
Shiloh I (CA)	Kerlinger et al. (2006*b*)	Kerlinger et al. (2009)
Shiloh II (CA)	Kerlinger et al. (2006*b*)	Kerlinger et al. (2010)
Stateline (OR and WA)	Erickson et al. (2003*a*)	Erickson et al. (2004)
Tuolumne (WA)	G. Johnson, Western EcoSystems Technology, Inc., unpublished data	T. Enz and K. Bay, Western EcoSystems Technology, Inc., unpublished data
Vansycle (OR)	Woodward-Clyde International-Americas and Western EcoSystems Technology, Inc., unpublished data	Erickson et al. (2000)
Vantage (WA)	Jeffrey et al. (2007)	Ventus Environmental Solutions, unpublished data
Vasco (CA)	Brown et al. (2013)	Brown et al. (2013)
Wessington Springs (SD)	C. Derby, Western EcoSystems Technology, Inc., unpublished data	C. Derby, unpublished data
White Creek (WA)	G. D. Johnson, unpublished data	S. Downes and R. Gritski, Northwest Wildlife Consultants, Incorporated, unpublished data
Wild Horse (WA)	Erickson et al. (2003*d*)	Erickson et al. (2008)
Windy Flats (WA)	Johnson et al. (2007)	T. Enz, unpublished data

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's website.