Appendix B

Bayesian Eagle Collision Risk Model

Biglow Canyon Wind Project

1.0 Overview

This appendix describes the details and assumptions of our modelling efforts that resulted in our fatality predictions for both eagle species for the Biglow Canyon Wind project. Although Alternatives 2 and 3 have different fatality predictions, they are both based on the annual fatality prediction described in this Appendix.

Since 141 of the 217 wind turbines at Biglow Canyon were constructed prior to September 11th, 2009, and since activities that were taking golden eagles prior to that date are already considered in our populations trends analysis (i.e. they are part of "baseline"; USFWS 2016), compensatory mitigation is required only for 76 of the 217 turbines at the Biglow Canyon Project. Thus, fatality predictions to inform the applicant's compensatory mitigation requirement from those 76 turbines are necessary. This Appendix also describes modelling details for those 76 turbines ONLY.

1.1 BACKGROUND

The Service uses explicit models in a Bayesian statistical framework to predict eagle fatalities at wind facilities while accounting for uncertainty. This model is hereafter referred to as the Collision Risk Model (CRM). The analysis presented below follows the Service's Eagle Conservation Plan Guidance version 2 (ECPG, USFWS 2013); a more detailed background on the Service's model and modelling framework are presented in Appendix D of the Technical Appendices of the ECPG.

The Service CRM is based on the assumption that there is a predictable relationship between pre-construction eagle exposure events (λ; eagle-minutes below 200m / hr·km^2) and subsequent annual fatalities resulting from collisions with wind turbines (F), such that:

$$\boldsymbol{F = \varepsilon \cdot \lambda \cdot C}$$

where C is the probability of a collision given one minute of eagle flight within the hazardous area (see definition in the ECPG technical appendices), and ε is the expansion factor, a constant that describes the total area (or volume) and time within a project footprint that is potentially hazardous to eagles; this is used to expand λC, the number of birds killed per minute of exposure, into the annual number of predicted fatalities.

One advantage of using a Bayesian modelling framework is the ability to incorporate existing knowledge directly into the model by defining an appropriate prior probability distribution (hereafter "prior"). The Service has defined a prior distribution for eagle exposure (*Gamma* (0.97, 2.76)) based on the exposure rates across a range of projects under Service review and others described with sufficient detail in Whitfield (2009), and has defined a prior for collision probability (*Beta* (2.31, 396.69)) based on information from projects presented in Whitfield (2009). These prior distributions are updated with data collected from the wind facility under consideration to obtain posterior distributions (hereafter "posterior") that provide the project specific estimates of λ and C. Specifically, the exposure prior can be updated with pre-construction eagle use data collected at a site (note: when adequate pre-construction survey efforts are performed, the relative influence of the λ prior distribution on the resulting posterior λ becomes negligible). The collision probability prior can also be updated with post-construction fatality estimates if/when a project becomes operational. Details on these priors and how to update them can be found in the ECPG (USFWS 2013).

2.0 CALCULATING MODEL VARIABLES

2.1 Exposure Rate Calculation (λ)

The exposure rate (λ) is defined in Appendix D of the Technical Appendices of the ECPG as the number of exposure events (eagle-minutes) per daylight hour per square kilometer. The exposure prior is defined in the ECPG as:

$$\textbf{Prior } \lambda \sim \textit{Gamma } (0.97,\ 2.76)$$

This prior assumes that the eagle use surveys collected data on the eagles flying between 0-200m above ground level. However, because many projects were constructed, or their pre-construction data collection completed, prior to the publication of the ECPG, pre-construction eagle survey methods are not always consistent with this assumption, which is laid out in the Service's recommendations in the ECPG. Exposure values calculated from data born from these surveys, especially where the 200m survey height was not achieved, may not be appropriate for use with the exposure prior as defined in the ECPG. However, deviations from the recommended survey height (i.e. survey ceilings less than or greater than 200m, or data only collected within a rotor swept zone) can be accomodated by re-defining the exposure rate as the number of exposure events per daylight hour per **volume (km^3)**, instead of square kilometer. When running the model with this three-dimensional exposure value, the exposure prior must be adjusted as below:

$$\textbf{Volumetric Prior } \lambda \sim \textit{Gamma } (0.968,\ 0.552)$$

For projects that performed surveys at the recommended 200m survey height, or that did not perform surveys at all (i.e. only exposure priors were used in modelling), it matters not which of the above priors are used in modelling, the model outputs are the same. However, where the range of heights surveyed was not 0-200m as recommended, the Volumetric Prior should be used to account for this deviation.

Site specific exposure rates can be used to update either exposure prior and determine a posterior distribution specific to a project area. The resulting posterior distribution (after updating the prior) is defined in the ECPG as:

$$\textbf{Posterior } \lambda \sim \textit{Gamma } (0.97 + \textstyle\sum_{i=1}^{n} ki,\ \ 2.76 + n)$$

or

$$\textbf{Volumetric Posterior } \lambda \sim \textit{Gamma } (0.968 + \textstyle\sum_{i=1}^{n} ki,\ \ 0.552 + n)$$

where *ki* is the summed number of eagle-minutes within the surveyed cylinder and where *n* represents the survey effort put forth – equal to either hr*km^2 (for the standard prior) or hr*km^3 (for the volumetric prior).

For Biglow Canyon, the Volumetric Prior was used throughout the modelling effort.

Pre-construction collection of eagle-use information in and around the Biglow Canyon Project began in March 2004 and continued through August 2006. For a variety of reasons, the most notable of which are listed below, these surveys were inconsistent with pre-construction survey recommendations in the

ECPG. *Note: These surveys were initiated and completed prior to the publication of formal pre-construction survey design recommendations from the Service.*

1) Only the number of eagle observations were documented, not the number of eagle-minutes.
2) Survey duration at each point was 30 minutes, which is short of the recommended minimum of 60 minutes.
3) Surveys were designed to document use of all avian species and not eagles specifically. A design that has the observer looking specifically for large raptors is recommended.

Nonetheless, these surveys were assumed to be adequate for use in updating the exposure prior.

Surveys documented 2 bald eagle observations (birds in flight) and 8 golden eagle observations (birds in flight) within 800m radius and within 200m height, during 266.5 hours of formal observation. To turn eagle observations into Eagle Minutes, we assumed that one eagle observation was equivalent to one eagle minute, as was expected in the ECPG, Appendix C. These observations and minutes for each species are depicted in Table 1, below.

Table 1: *Eagle Observations for each eagle species. Resulting eagle-minutes (yellow cells), assuming one eagle-minute per observation, were used to update the exposure prior for each species.*

Survey Dates	# of Surveys	Survey Length (Mins)	Bald Eagle		Golden Eagle	
			# Obs	EMins	# Obs	EMins
2004-2006	533	30	2	2	8	8

The code presented in Attachment A to this Appendix is written to calculate posterior distributions for exposure, using the values in Table 1 and realized search plot dimensions; however, the posterior can also be calculated by hand as described for each species below.

BALD EAGLE

$$\text{Volumetric Posterior } \lambda \sim \textit{Gamma}\,(0.968 + 2\text{ EMins},\; 0.552 + (533\text{ counts} \cdot 0.5\text{hr} \cdot \pi(0.8\text{km})^2 \cdot 0.2\text{km})))$$

$$\mathbf{Volumetric\ Posterior}\ \boldsymbol{\lambda \sim \textit{Gamma}}\ \mathbf{(2.968,\ 107.718)}$$

GOLDEN EAGLE

$$\text{Volumetric Posterior } \lambda \sim \textit{Gamma}\,(0.968 + 8\text{ EMins},\; 0.552 + (533\text{ counts} \cdot 0.5\text{hr} \cdot \pi(0.8\text{km})^2 \cdot 0.2\text{km})))$$

$$\mathbf{Volumetric\ Posterior}\ \boldsymbol{\lambda \sim \textit{Gamma}}\ \mathbf{(8.968,\ 107.718)}$$

2.2 Collision probability calculation (C)

The probability of collision (C) is the probability of an eagle colliding with a turbine for each minute of exposure (eagle-minutes in the hazardous area). The collision probability prior distribution is defined in Appendix D of the Technical Appendices of the ECPG as:

Prior *C* ~ *Beta* (2.31, 396.69)

After construction, site-specific estimates of fatalities, based on post-construction fatality monitoring (PCM), can be used to update the collision probability prior. The posterior distribution (after updating of the prior) can be simply expressed[1] as:

Posterior *C* ~ *Beta* (2.31 + *f*, 396.69 + *g*)

where f is the number of fatalities estimated to have occurred at the project and g is the estimated number of exposure events (represented by the exposure distribution) that did not result in a fatality. Once determined, this posterior distribution replaces the national collision probability prior in the model and can serve as a new prior for subsequent updates as new PCM data is collected and fatality estimates derived.

PCM at Biglow was done in phases, consistent with the phased development of the project, with two years of PCM performed at each phase, beginning after the completion of each phase. However, since the different phases did not become operational at regular intervals, there were several periods of time where PCM at one phase partially overlapped PCM at another. Also, survey methods changed slightly between phases. Such a PCM design, where the proportion of unsearched area (because of added turbines) and effort (starting and stopping of some PCM) were occasionally changing mid-year, made estimating fatalities at the project, and doing annual collision probability prior updates, difficult. To make sense of the situation, we separated the PCM period into six “Analysis Periods” (Table 2). Due to the timing of turbine construction in different phases, these analysis periods were not always one year in duration, but the fatality estimate derived for each period was always converted to an annual estimate for the purposes of updating the collision probability prior. In total, five updates were performed to the collision probability prior using five annual fatality estimates (Table 3), with the posterior from the fifth update finally used to run the model and predict eagle fatalities.

The fatality estimates from each Analysis Period was calculated using fatality CMR (FCMR) and are listed in Table 2. Inputs and bias trial data files used in the creation of these estimates are provided in Attachment B of this Appendix. The FCMR software and details on the FCMR estimator can be downloaded online at https://www.mbr-pwrc.usgs.gov/software/fatalityCMR.shtml.

General assumptions made during FCMR fatality estimation:

1) That each 110 x 110m search plot encompassed 50% of the area where an eagle carcass could be found around each turbine. This value was based on conclusions in Hull and Muir (2010) and used when running FCMR for Analysis Period 1 and 2.
2) That each 125 x 125m search plot encompassed 57% of the area where an eagle carcass could be found around each turbine. This value was based on conclusions in Hull and Muir (2010) and used when running FCMR for Analysis Period 5 and 6.

[1] Values in the equations are simplified to promote understanding. Actual parameters used in updated collision probability distributions were calculated using the R code attached below with functions provided with New *et al.* (2015) – see supporting information (https://doi.org/10.1371/journal.pone.0130978.s001).

3) That the area searched in Analysis Period 3 was equivalent to the average of the two search plot sizes, rounded up to the nearest integer – (0.50 + 0.57) / 2 = 0.535 (rounds to 0.54)

Table 2: *Summary of Analysis Periods and resulting eagle fatality estimates (yellow cells) for those periods.*

Analysis Period	Start/End Date (Duration[$])	Turbines in Existence	Turbines Searched	Propotion of Carcass Distribution Searched	BAEA Carcasses Found	GOEA Carcasses Found	BAEA Annual Fatality Estimate[*]	GOEA Annual Fatality Estimate[*]
1	1/10/08 – 12/12/08 (306 days)	76	50	0.50	0	0	0.175	0.239
2	1/26/09 – 9/5/09 (210 days)	76	50	0.50	0	0	0.175	0.175
3	9/5/09 – 12/11/09 (77 days)	141	100	0.54[!]	0	0	0.271	0.271
4	12/11/09 – 9/12/10 (276 days)	141	50	0.57	0	0	1.379	1.379
5	9/13/10 – 9/15/11 (349 days)	217	100	0.57	0	0	0.663	0.663
6	9/19/11 – 9/18/12 (352 days)	217	50	0.57	0	0	1.336	1.336

[$] Duration is the number of effective days (i.e. days the corresponding fatality estimate represents). This was calculated by averaging the average number of days between the first search and the last search at all searched turbines during the analysis period.
! This value was calculated by taking the average proportion between the two search plot sizes used in this Analysis Period
[*] Estimates account for biases from imperfect searcher efficiency, unsearched areas, and carcass removal rates – site-specific data on these biases were collected during years 1 and 2. See Attachment A for more details.

Analysis Periods 3 and 4 were combined into one period for the purposes of updating the collision probability prior. This was done by summing the estimates from Analysis Period 3 and 4. Thus, there were five updates to the collision probability prior performed for each species using the five different site-specific fatality estimates in Table 3 – one update for each species for each period of fatality monitoring. Note that, since no eagle carcasses of either species were discovered during any PCM, the fatality estimates for those periods are identical for both species (Table 3). Thus, the collision probability prior will be updated using the same fatality estimates for both species as outlined below.

Table 3: *Summary of Annual Fatality Estimates derived from each analysis period and used for serially updating the collision probability prior – yellow cells.*

Analysis Period	Duration[$]	Unadjusted Fatality Estimate[$]	Annual Eagle Fatality Estimate[*]
1	306 days	0.239	0.285
2	210 days	0.175	0.304
3	77 days	0.271	1.706
4	276 days	1.379	
5	349 days	0.663	0.693
6	352 days	1.336	1.385

[!] Duration is the number of effective days (i.e. days the corresponding fatality estimate represents). This was calculated by averaging the average number of days between the first search and the last search at all searched turbines during the analysis period.
[$] The fatality estimate for the number of days in each Analysis Period, prior to adjusting it to represent a full year.
[*] The fatality estimate for a full year (365 days). Estimates account for biases from imperfect searcher efficiency, unsearched areas, and carcass removal rates – site-specific data on these biases were collected during years 1 and 2. See Attachment A for more details.

Parameters of the posterior distributions resulting from each of the five serial updates for each species are listed below, as calculated using the code in Attachment A. These parameters describe the collision probability posteriors for each species after each serial update. Each posterior becomes the new collision probability distribution to be used in the subsequent update. Posterior C5 for each species represents the most up to date collision probability prior distribution for that species and is used to derive the fatality predictions below (see Bayesian Model Inputs and Calculations Section). Note that, despite the use of the same fatality estimates in these updates, the parameters are notably different for each eagle species. This is because the beta-parameter is derived using the exposure distribution, which is different for each species.

BALD EAGLE

Posterior *C1* ~ *Beta* (2.622, 411.087)

Posterior *C2* ~ *Beta* (2.934, 422.305)

Posterior *C3* ~ *Beta* (4.643, 442.263)

Posterior *C4* ~ *Beta* (5.328, 472.594)

Posterior *C5* ~ *Beta* (6.702, 504.617)

GOLDEN EAGLE

Posterior *C1* ~ *Beta* (2.591, 424.572)

Posterior *C2* ~ *Beta* (2.874, 450.141)

Posterior *C3* ~ *Beta* (4.599, 513.608)

Posterior *C4* ~ *Beta* (5.298, 613.849)

Posterior *C5* ~ *Beta* (6.713, 716.169)

2.3 Expansion Factor Calculation (ε)

The expansion factor (ε) scales the resulting per unit fatality rate (fatalities per hr per km^2) to the daylight hours in one year (or other time period if desired) and total hazardous area within the project footprint. Since the Volumetric Exposure Prior is being used, the expansion factor must use a fatality rate that accounts for survey height (fatalities per hr per km^3) and accounts for volume of the hazardous area (km^3). Thus, the expansion factor is defined as the product of the total hazardous volume ($\delta = \pi \cdot r^2 \cdot h$, where r is the turbine rotor radius, h is 200 meters) and δ is summed across all turbines (nt = number of turbines) and daylight hours (τ).

$$\boldsymbol{\varepsilon = \tau \cdot \sum_{i=1}^{nt} \delta i}$$

The total number of daylight hours over any 1-year period at Biglow Canyon Wind is estimated to be 4465.26 hours. The turbine size differed between phases, with Phase 1 consisting of turbines with a rotor swept radius of 41 meters and Phases 2 and 3 consisting of turbines with a rotor swept radius of 46.5 meters. Thus, the following expansion factors were used for each respective phase of the project. The overall expansion factor used in the model was the sum of the two factors for each turbine.

PHASE 1

$$\varepsilon = 4465.26\text{hr} \cdot (\pi \cdot (0.041\text{km}^2) \cdot 0.200\text{km}) \cdot 76 = \mathbf{358.43\ hr{\cdot}km^3}$$

PHASES 2 and 3

$$\varepsilon = 4465.26\text{hr} \cdot (\pi \cdot (0.0465\text{km}^2) \cdot 0.200\text{km}) \cdot 141 = \mathbf{855.37\ hr{\cdot}km^3}$$

OVERALL

$$358.43 + 855.37 = \mathbf{1213.80\ hr{\cdot}km^3}$$

2.3.1 Golden Eagle Compensatory Mitigation Requirement

To assist us with calculating the applicant's compensatory mitigation requirement, we included a CRM run that predicts take of golden eagles from only 76 of the 217 project turbines. Since these 76 turbines have a rotor swept radius of 46.5 meters, the expansion factor for this model run was calculated the same as it was above, for Phases 2 and 3, except instead of modelling predicted golden eagle fatalities for the whole project, the number of turbines was set to 76. The most up to date collision probability posterior distribution for golden eagles (Posterior C5) was used when conducting these modelling efforts.

3.0 BAYESIAN MODEL R-CODE INPUTS

The Tables that follow summarize the model inputs for each species. Many of these inputs are described above, but are mentioned again here to coincide with the R-code given in Attachment A, in the order they appear in the code.

***Table 4:** Summary of CRM inputs for both species at the entire project*

	BALD EAGLE	GOLDEN EAGLE	Notes
Number of Simulations	100,000		
# of Turbines	76, 141		76 with 41m radius; 141 with 46.5m radius
Hazardous Radius (km)	0.041, 0.0465		40m radius
Count Duration (hrs)	0.5		30 minutes
Number of Counts	533		Totals 266.5 hours of survey effort
Eagle Minutes	2	8	
Operational Daylight Hrs (hrs)	4465.26		Assuming operation during all daylight hrs
Exposure Prob. Alpha Parameter	0.9684375	0.9684375	Un-updated Volumetric Exposure Prob. Prior: see Section 2.1
Exposure Prob. Beta Parameter	0.5519703	0.5519703	
Collision Prob. Alpha Parameter	6.702	6.713	Updated Collision Prob.: Derived as described in Section 2.2
Collision Prob. Beta Parameter	504.617	716.169	

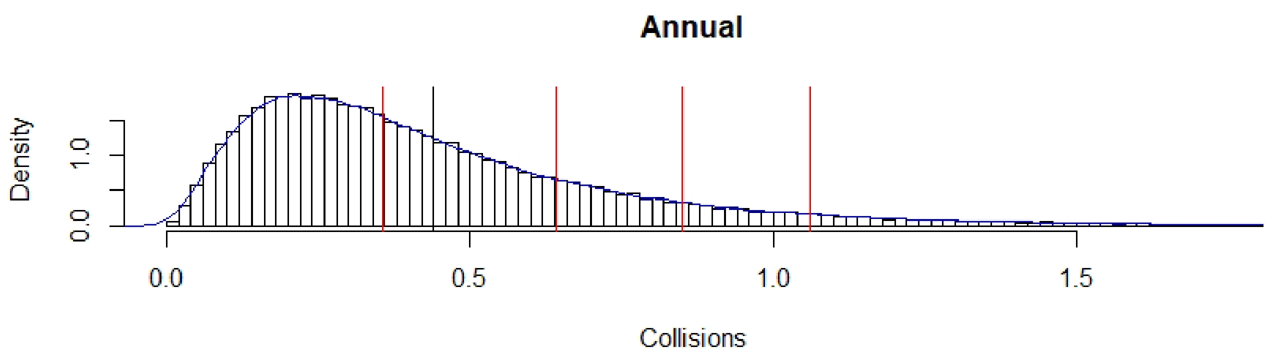
***Table 5:** Summary of CRM inputs for golden eagles at 76 project turbines (with rotor swept radius of 46.5m)– to inform the compensatory mitigation requirement.*

	GOLDEN EAGLE	Notes
Number of Simulations	100,000	
# of Turbines	76	Only turbs that began operating after 9/11/09
Hazardous Radius (km)	0.0465	46.5m radius
Count Duration (hrs)	0.5	30 minutes
Number of Counts	533	Totals 103.5 hrs of survey effort
Eagle Minutes	8	
Operational Daylight Hrs (hrs)	4465.26	Assuming operation during all daylight hrs
Exposure Prob. Alpha Parameter	0.9684375	Un-updated Volumetric Exposure Prob. Prior: see Section 2.1
Exposure Prob. Beta Parameter	0.5519703	
Collision Prob. Alpha Parameter	6.713	Updated Collision Prob. Prior: Derived as described in Section 2.2
Collision Prob. Beta Parameter	716.169	

4.0 RUNNING THE BAYESIAN MODEL

As described in Appendix D of the Technical Appendices of the ECPG, Service's Bayesian model calculates predicted fatalities using Gibbs sampling. As a result, the mathematical form of the posterior distribution is known because the distributions specified for the data and the prior are in the same family (known as conjugacy). To make inference on the parameters of interest (exposure and collision in this case), values are drawn from the mathematical representation of the exposure posteriors and collision probability posteriors described above (*n* = 100,000 for Biglow Canyon Wind) in order to obtain the posterior distribution of predicted fatalities. Distributions of predicted fatalities for each species at the Biglow Canyon Wind facility are depicted in the Figures below. Model results for each species, including the mean, standard deviation (SD), median (Q50), and 80th, 90th, and 95th quantiles (Q80, Q90, and Q95, respectively) are depicted in Table 5. Table 6 depicts the results of the golden eagle models, but only for the 76 project turbines for which compensatory mitigation will be required.

<u>Bald Eagles</u>



<u>Golden Eagles</u>

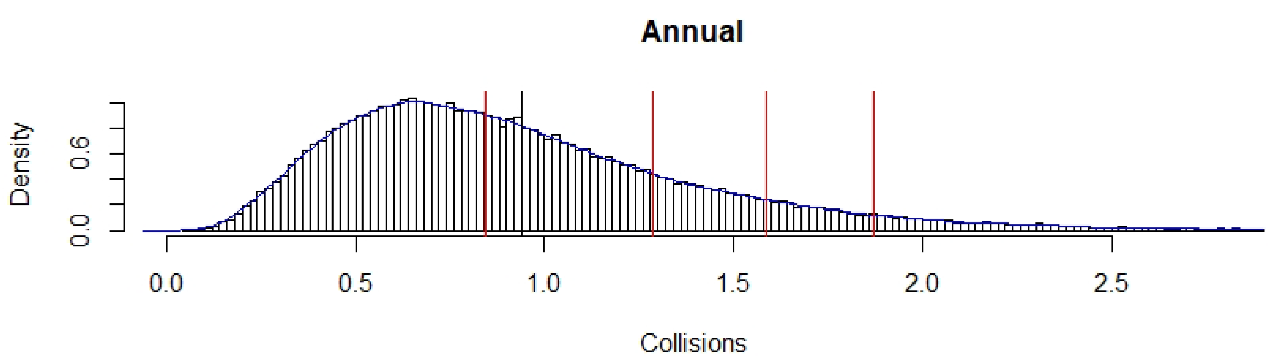


Figure 1: Predicted eagle fatalities (top: bald eagle; bottom; golden eagle). The red vertical lines represent the 50th, 80th, 90th, and 95th quantiles (from left to right) of the distribution. The black line in each graph depicts the mean annual fatality prediction. The 80th quantile is the value the Service uses as a prediction of eagle fatalities.

Table 6: Summary of model outputs (take predictions in units 'eagles per year') for each species at the entire project. Outputs include the mean, standard deviation (SD), median (Q50), 80th quantile (Q80), 90th quantile (Q90), and 95th quantile (Q95) for each species. Yellow outputs will be used to calculate the predicted take for all 217 turbines over the permit tenure.

	Bald Eagles		**Golden Eagles**

	Mea n	SD	Q50	Q80	Q90	Q95		Mean	SD	Q50	Q80	Q90	Q95
Annual Prediction	0.44	0.32	0.36	0.64	0.85	1.06		0.94	0.49	0.84	1.28	1.59	1.88

Table 7: Summary of model outputs (take predictions in units 'eagles per year') for golden eagles only at the 76 project turbines that became operational after Sept 11, 2009. Outputs include the mean, standard deviation (SD), median (Q50), 80th quantile (Q80), 90th quantile (Q90), and 95th quantile (Q95). Yellow outputs will be used to calculate the compensatory mitigation requirement for offsetting take of golden eagles.

	Golden Eagles					
	Mea n	SD	Q50	Q80	Q90	Q95
Annual Prediction	0.36	0.19	0.32	0.49	0.60	0.71

5.0 CONCLUSIONS

5.1 Authorized Take at Biglow Canyon Wind

Annual fatality predictions calculated and depicted in Table 6 were used to calculate the amount of eagle take to be authorized over the tenure of a 5-year (Alternative 2) and a 30-year (Alternative 3) Eagle Incidental Take Permit. Our modelling predicts, at the 80th quantile, that 0.64 bald eagles and 1.28 golden eagles will be killed annually at the Biglow Canyon Wind Project. Over five years, this annual prediction equates to 3.2 bald eagles and 6.4 golden eagles. Over thirty years, this annual prediction equates to 19.2 bald eagles and 38.4 golden eagles. If a 5-year authorization is given for this project, the Service would round these numbers up to the nearest whole number and authorize the incidental take of 4 bald eagles and 7 golden eagles. Similarly, if a 30-year eagle take authorization is given for this project, the Service would authorize the incidental take of 20 bald eagles and 39 golden eagles over the 30-year permit term.

5.2 Golden Eagle Compensatory Mitigation Requirement

Annual fatality predictions calculated and depicted in Table 7 were used to calculate the amount of golden eagle take that would need to be offset by compensatory mitigation over the tenure of a 5-year Eagle Incidental Take Permit. The modelling predicts, at the 80th quantile, that 0.49 golden eagles will be killed annually at the 76 turbines that became operational after Sept 11, 2009. Over five years (the initial term that upfront mitigation is required for), that equates to 2.45 golden eagles. If an eagle take authorization is given for this project, the Service would round this number up to the nearest whole number and require compensatory mitigation be provided for the take of 3 golden eagles over the first 5 years of the permit term.

LITERATURE CITED

Hull, C.L., and S. Muir. 2010. Search areas for monitoring bird and bat carcasses at wind farms using a Monte-Carlo model. *Australian Journal of Environmental Management* 17: 77-87.

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USFWS. 2016. Bald and Golden Eagles: Population demographics and estimation of sustainable take in the United States, 2016 update. U.S. Fish and Wildlife Service Division of Migratory Bird Management, Washington D.C., USA.

Whitfield, D. P. 2009. Collision avoidance of golden eagles at wind farms under the 'Band' collision risk model. Report from Natural Research to Scottish Natural Heritage, Banchory, UK.

ATTACHMENT A: R-Code

This attachment presents the R-code used to serially update the collision probability prior and, ultimately, run the Service's CRM for each species to get a fatality prediction for the entire project (217 turbines) and for the 76 turbine that became operational after Sept 11, 2009 (to calculate compensatory mitigation). Sourced files can be found in New *et al.* (2015) – see supporting information (https://doi.org/10.1371/journal.pone.0130978.s001). Code is presented for Golden Eagles only. The same code was used for bald eagles except with different inputs as described in this Appendix.

Collision Probability Prior Update #1:

Instructions: Enter fatality estimate from Analysis Period 1 (Table 3) to inform yellow code. Run code above red line, use outputs to inform code in pink (mean) and blue (SD). Run code below red line and use outputs to inform green code (alpha) and in red code (beta) the next update.

```
source("C:/Users/mstuber/Eagle_FatalityModel_Code/RVSmry.R")
source("C:/Users/mstuber/Eagle_FatalityModel_Code/FatalFcns.R")
source("C:/Users/mstuber/Eagle_FatalityModel_Code/MEEsimFatal.R")
require(rv)
UCI<-c(0.5,0.8,0.9,0.95)
nSim<-100000
nTurbine<-c(76)
HazRadKm<-c(41/1000)
HazKM3<-c(nTurbine*0.2*pi*HazRadKm^2)
CntHr<-c(30/60)
ExpSvy<-data.frame(row.names=c("Annual"),
EMin=c(8),
nCnt=c(533),
CntKM3=c(0.2*pi*0.8^2),
DayLtHr<-c(4465.26))
Dead<-c(0.2845)
AddTot<-TRUE
setnsims(nSim)
getnsims()
PlotFile<-NULL
nSvy<-nrow(ExpSvy)
cSvy<-(rownames(ExpSvy))
SmpHrKM3<-c(ExpSvy$nCnt*CntHr*ExpSvy$CntKM3)
ExpFac<-c(ExpSvy$DayLtHr*HazKM3)
postBH1<-simFatal(BMin=ExpSvy$EMin, Fatal = Dead, SmpHrKm=SmpHrKM3, ExpFac=ExpFac,
aPriExp=0.9684375,bPriExp=0.5519703,
aPriCPr=2.31,bPriCPr=396.69)
postCPr<-attr(postBH1,"CPr")
postCPr
---------------------------------------------------------------------------------------------------------
estBetaParams <- function(mu, var) {
 alpha <- ((1 - mu) / var - 1 / mu) * mu ^ 2
 beta <- alpha * (1 / mu - 1)
 return(params = list(alpha = alpha, beta = beta))
}
estBetaParams(0.006065118,0.003752272^2)
```

Collision Probability Prior Update #2:

Instructions: Enter fatality estimate from Analysis Period 2 (Table 3) to inform yellow code. Run code above red *line, use outputs to inform code in pink (mean) and blue (SD). Run code below red line and use outputs to inform green code (alpha) and in red code (beta) the next update.*

```
require(rv)
UCI<-c(0.5,0.8,0.9,0.95)
nSim<-100000
nTurbine<-c(76)
HazRadKm<-c(41/1000)
HazKM3<-c(nTurbine*0.2*pi*HazRadKm^2)
CntHr<-c(30/60)
ExpSvy<-data.frame(row.names=c("Annual"),
EMin=c(8),
nCnt=c(533),
CntKM3=c(0.2*pi*0.8^2),
DayLtHr<-c(4465.26))
Dead<-c(0.3038)
AddTot<-TRUE
setnsims(nSim)
getnsims()
PlotFile<-NULL
nSvy<-nrow(ExpSvy)
cSvy<-(rownames(ExpSvy))
SmpHrKM3<-c(ExpSvy$nCnt*CntHr*ExpSvy$CntKM3)
ExpFac<-c(ExpSvy$DayLtHr*HazKM3)
postBH1<-simFatal(BMin=ExpSvy$EMin, Fatal = Dead, SmpHrKm=SmpHrKM3, ExpFac=ExpFac,
aPriExp=0.9684375,bPriExp=0.5519703,
aPriCPr=2.591,bPriCPr=424.5716)
postCPr<-attr(postBH1,"CPr")
postCPr
-----------------------------------------------------------------------------------------------------------
estBetaParams <- function(mu, var) {
  alpha <- ((1 - mu) / var - 1 / mu) * mu ^ 2
  beta <- alpha * (1 / mu - 1)
  return(params = list(alpha = alpha, beta = beta))
}
estBetaParams(0.006343209,0.003725957^2)
```

Collision Probability Prior Update #3:

Instructions: Enter fatality estimate from Analysis Period 3 (Table 3) to inform yellow code. Run code above red line, use outputs to inform code in pink (mean) and blue (SD). Run code below red line and use outputs to inform green code (alpha) and in red code (beta) the next update.

```
require(rv)
```

```
UCI<-c(0.5,0.8,0.9,0.95)
nSim<-100000
nTurbine<-c(76, 65)
HazRadKm<-c(41/1000, 46.5/1000)
HazKM3<-c(nTurbine*0.2*pi*HazRadKm^2)
CntHr<-c(30/60)
ExpSvy<-data.frame(row.names=c("Annual"),
EMin=c(8),
nCnt=c(533),
CntKM3=c(0.2*pi*0.8^2),
DayLtHr<-c(4465.26))
Dead<-c(1.7059)
AddTot<-TRUE
setnsims(nSim)
getnsims()
PlotFile<-NULL
nSvy<-nrow(ExpSvy)
cSvy<-(rownames(ExpSvy))
SmpHrKM3<-c(ExpSvy$nCnt*CntHr*ExpSvy$CntKM3)
ExpFac<-c(ExpSvy$DayLtHr*HazKM3)
postBH1<-simFatal(BMin=ExpSvy$EMin, Fatal = Dead, SmpHrKm=SmpHrKM3, ExpFac=ExpFac,
aPriExp=0.9684375,bPriExp=0.5519703,
aPriCPr=2.873566,bPriCPr=450.141)
postCPr<-attr(postBH1,"CPr")
postCPr
```

```
estBetaParams <- function(mu, var) {
  alpha <- ((1 - mu) / var - 1 / mu) * mu ^ 2
  beta <- alpha * (1 / mu - 1)
  return(params = list(alpha = alpha, beta = beta))
}
estBetaParams(0.008874333,0.004115873^2)
```

Collision Probability Prior Update #4:

Instructions: Enter fatality estimate from Analysis Period 4 (Table 3) to inform yellow code. Run code above red line, use outputs to inform code in pink (mean) and blue (SD). Run code below red line and use outputs to inform green code (alpha) and in red code (beta) the final fatality prediction in the next step.

```
require(rv)
UCI<-c(0.5,0.8,0.9,0.95)
nSim<-100000
nTurbine<-c(76, 141)
```

```
HazRadKm<-c(41/1000, 46.5/1000)
HazKM3<-c(nTurbine*0.2*pi*HazRadKm^2)
CntHr<-c(30/60)
ExpSvy<-data.frame(row.names=c("Annual"),
EMin=c(8),
nCnt=c(533),
CntKM3=c(0.2*pi*0.8^2),
DayLtHr<-c(4465.26))
Dead<-c(0.6934)
AddTot<-TRUE
setnsims(nSim)
getnsims()
PlotFile<-NULL
nSvy<-nrow(ExpSvy)
cSvy<-(rownames(ExpSvy))
SmpHrKM3<-c(ExpSvy$nCnt*CntHr*ExpSvy$CntKM3)
ExpFac<-c(ExpSvy$DayLtHr*HazKM3)
postBH1<-simFatal(BMin=ExpSvy$EMin, Fatal = Dead, SmpHrKm=SmpHrKM3, ExpFac=ExpFac,
aPriExp=0.9684375,bPriExp=0.5519703,
aPriCPr=4.598741,bPriCPr=513.6082)
postCPr<-attr(postBH1,"CPr")
postCPr
```

```
estBetaParams <- function(mu, var) {
  alpha <- ((1 - mu) / var - 1 / mu) * mu ^ 2
  beta <- alpha * (1 / mu - 1)
  return(params = list(alpha = alpha, beta = beta))
}
estBetaParams(0.008557389,0.003698767^2)
```

<u>Collision Probability Prior Update #5:</u>

Instructions: Enter fatality estimate from Analysis Period 5 (Table 3) to inform yellow code. Run code above red line, use outputs to inform code in pink (mean) and blue (SD). Run code below red line and use outputs to inform green code (alpha) and in red code (beta) the final fatality prediction in the next step.

```
require(rv)
UCI<-c(0.5,0.8,0.9,0.95)
nSim<-100000
nTurbine<-c(76, 141)
HazRadKm<-c(41/1000, 46.5/1000)
HazKM3<-c(nTurbine*0.2*pi*HazRadKm^2)
CntHr<-c(30/60)
```

```
ExpSvy<-data.frame(row.names=c("Annual"),
EMin=c(8),
nCnt=c(533),
CntKM3=c(0.2*pi*0.8^2),
DayLtHr<-c(4465.26))
Dead<-c(1.3850)
AddTot<-TRUE
setnsims(nSim)
getnsims()
PlotFile<-NULL
nSvy<-nrow(ExpSvy)
cSvy<-(rownames(ExpSvy))
SmpHrKM3<-c(ExpSvy$nCnt*CntHr*ExpSvy$CntKM3)
ExpFac<-c(ExpSvy$DayLtHr*HazKM3)
postBH1<-simFatal(BMin=ExpSvy$EMin, Fatal = Dead, SmpHrKm=SmpHrKM3, ExpFac=ExpFac,
aPriExp=0.9684375,bPriExp=0.5519703,
aPriCPr=5.298285,bPriCPr=613.8491)
postCPr<-attr(postBH1,"CPr")
postCPr
```

```
estBetaParams <- function(mu, var) {
  alpha <- ((1 - mu) / var - 1 / mu) * mu ^ 2
  beta <- alpha * (1 / mu - 1)
  return(params = list(alpha = alpha, beta = beta))
}
estBetaParams(0.009286782,0.003565107^2)
```

<u>Fatality Prediction:</u>

Instructions: Update collision probability distribution alpha (green) and beta (red) values from the most recent collision probability distribution update. Run the code.

```
require(rv)
UCI<-c(0.5,0.8,0.9,0.95)
nSim<-100000
ModelDescription<-"Biglow Canyon Wind"
nTurbine<-c(76,141)
HazRadKm<-c(41/1000, 46.5/1000)
HazKM3<-sum(nTurbine*0.2*pi*HazRadKm^2)
CntHr<-c(30/60)
ExpSvy<-data.frame(row.names=c("Annual"),
EMin=c(8),
nCnt=c(533),
```

```
CntKM3=c(0.2*pi*0.8^2),
DayLtHr<-c(4465.26))
AddTot<-TRUE
setnsims(nSim)
getnsims()
PlotFile<-NULL
nSvy<-nrow(ExpSvy)
cSvy<-(rownames(ExpSvy))
SmpHrKM3<-with(ExpSvy,nCnt*CntHr*CntKM3)
ExpFac<-c(DayLtHr*HazKM3)
tmp<-with(ExpSvy,mapply(simFatal,BMin=EMin, Fatal = -1, SmpHrKm=SmpHrKM3, ExpFac=ExpFac,
aPriExp=0.9684375,bPriExp=0.5519703,
aPriCPr=6.713252,bPriCPr=716.1692,SIMPLIFY=FALSE))
Fatalities<-rvnorm(nSvy)
Exp<-data.frame(Mean=rep(NA,nSvy),SD=NA,row.names=cSvy)
for(i in 1:nSvy){Fatalities[i]<-tmp[[i]]  Exp[i,]<-attr(tmp[[i]],"Exp")}
rm(tmp)
names(Fatalities)<-cSvy
nSvy<-length(Fatalities)
if(is.null(nSvy))nSvy<-1
FatalStats<-RVSmry(cSvy,Fatalities,probs=UCI)
if(AddTot){FatalStats<-rbind(FatalStats,RVSmry("Total",sum(Fatalities),probs=UCI))}
print(ExpSvy)
print(Exp,digits=3)
print(FatalStats,digits=3)
nPlot<-nSvy+as.integer(AddTot)
nCol<-floor(sqrt(nPlot))
nRow<-ceiling(nPlot/nCol)
xlim<-range(rvrange(Fatalities))
if(!is.null(PlotFile))jpeg(PlotFile)
par(mfrow=c(nRow,nCol))
for(iPlot in 1:nSvy){plotFatal(Fatalities[iPlot],probs=UCI,main=cSvy[iPlot])}
if(AddTot)plotFatal(sum(Fatalities),main="Total")
if(!is.null(PlotFile))dev.off()
```

Prediction Used to Calculate Compensatory Mitigation:

Instructions: Use the collision probability distribution alpha (green) and beta (red) values from the most recent collision probability distribution update. Run the code.

```
require(rv)
UCI<-c(0.5,0.8,0.9,0.95)
nSim<-100000
ModelDescription<-"Biglow Canyon Wind – Mitigation Calculation"
nTurbine<-c(76)
HazRadKm<-c(46.5/1000)
HazKM3<-sum(nTurbine*0.2*pi*HazRadKm^2)
CntHr<-c(30/60)
ExpSvy<-data.frame(row.names=c("Annual"),
EMin=c(8),
nCnt=c(533),
CntKM3=c(0.2*pi*0.8^2),
DayLtHr<-c(4465.26))
AddTot<-TRUE
setnsims(nSim)
getnsims()
```

```
PlotFile<-NULL
nSvy<-nrow(ExpSvy)
cSvy<-(rownames(ExpSvy))
SmpHrKM3<-with(ExpSvy,nCnt*CntHr*CntKM3)
ExpFac<-c(DayLtHr*HazKM3)
tmp<-with(ExpSvy,mapply(simFatal,BMin=EMin, Fatal = -1, SmpHrKm=SmpHrKM3, ExpFac=ExpFac,
aPriExp=0.9684375,bPriExp=0.5519703,
aPriCPr=6.713252,bPriCPr=716.1692,SIMPLIFY=FALSE))
Fatalities<-rvnorm(nSvy)
Exp<-data.frame(Mean=rep(NA,nSvy),SD=NA,row.names=cSvy)
for(i in 1:nSvy){Fatalities[i]<-tmp[[i]]  Exp[i,]<-attr(tmp[[i]],"Exp")}
rm(tmp)
names(Fatalities)<-cSvy
nSvy<-length(Fatalities)
if(is.null(nSvy))nSvy<-1
FatalStats<-RVSmry(cSvy,Fatalities,probs=UCI)
if(AddTot){FatalStats<-rbind(FatalStats,RVSmry("Total",sum(Fatalities),probs=UCI))}
print(ExpSvy)
print(Exp,digits=3)
print(FatalStats,digits=3)
nPlot<-nSvy+as.integer(AddTot)
nCol<-floor(sqrt(nPlot))
nRow<-ceiling(nPlot/nCol)
xlim<-range(rvrange(Fatalities))
if(!is.null(PlotFile))jpeg(PlotFile)
par(mfrow=c(nRow,nCol))
for(iPlot in 1:nSvy){plotFatal(Fatalities[iPlot],probs=UCI,main=cSvy[iPlot])}
if(AddTot)plotFatal(sum(Fatalities),main="Total")
if(!is.null(PlotFile))dev.off()
```

ATTACHMENT B: FCMR Input Files

This attachment presents several input tables (spreadsheets) used to arrive at the fatality estimates using FCMR. Persistence Trial and Detection Trial Data were used for each model run for both species. Since no carcasses were found during PCM, Search Data and FCMR inputs (and the resulting fatality estimates for each analysis period) were the same for both species.

<u>Persistence Trial Data:</u>

State	Type	duration	transition
State1	Type1	7	NA
State1	Type1	4	NA
State1	Type1	7	NA
State1	Type1	7	NA
State1	Type1	0	NA
State1	Type1	7	NA
State1	Type1	0	NA
State1	Type1	7	NA

State1	Type1	4	NA
State1	Type1	0	NA
State1	Type1	7	NA
State1	Type1	14	NA
State1	Type1	0	NA
State1	Type1	40	NA
State1	Type1	7	NA
State1	Type1	20	NA
State1	Type1	4	NA
State1	Type1	14	NA
State1	Type1	20	NA
State1	Type1	0	NA
State1	Type1	4	NA
State1	Type1	30	NA
State1	Type1	4	NA
State1	Type1	4	NA
State1	Type1	40	NA
State1	Type1	0	NA
State1	Type1	40	NA
State1	Type1	14	NA
State1	Type1	0	NA
State1	Type1	30	NA
State1	Type1	30	NA
State1	Type1	20	NA
State1	Type1	3	NA
State1	Type1	7	NA
State1	Type1	0	NA
State1	Type1	30	NA
State1	Type1	4	NA
State1	Type1	0	NA
State1	Type1	10	NA
State1	Type1	20	NA
State1	Type1	3	NA
State1	Type1	40	NA
State1	Type1	30	NA
State1	Type1	0	NA
State1	Type1	4	NA
State1	Type1	40	NA
State1	Type1	10	NA
State1	Type1	20	NA
State1	Type1	0	NA
State1	Type1	30	NA
State1	Type1	7	NA

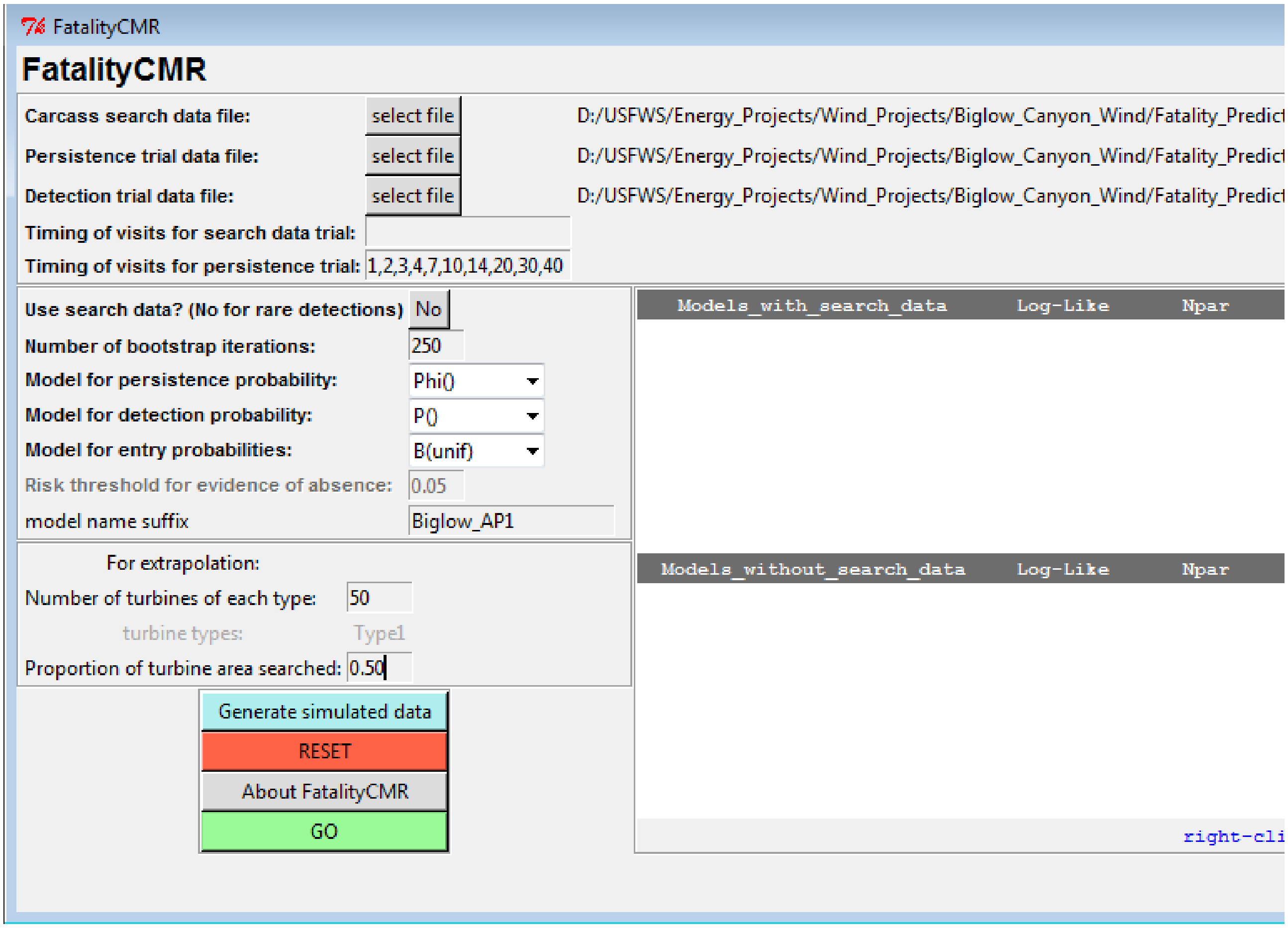
State1	Type1	4	NA
State1	Type1	7	NA
State1	Type1	7	NA
State1	Type1	20	NA
State1	Type1	7	NA
State1	Type1	0	NA
State1	Type1	7	NA
State1	Type1	10	NA
State1	Type1	1	NA
State1	Type1	7	NA
State1	Type1	4	NA
State1	Type1	3	NA
State1	Type1	3	NA
State1	Type1	0	NA
State1	Type1	4	NA
State1	Type1	0	NA
State1	Type1	40	NA
State1	Type1	4	NA
State1	Type1	4	NA
State1	Type1	20	NA
State1	Type1	30	NA
State1	Type1	30	NA
State1	Type1	4	NA
State1	Type1	7	NA
State1	Type1	2	NA
State1	Type1	4	NA
State1	Type1	40	NA
State1	Type1	40	NA
State1	Type1	1	NA
State1	Type1	40	NA
State1	Type1	14	NA
State1	Type1	7	NA
State1	Type1	14	NA
State1	Type1	40	NA
State1	Type1	40	NA
State1	Type1	40	NA
State1	Type1	7	NA
State1	Type1	10	NA
State1	Type1	40	NA
State1	Type1	1	NA
State1	Type1	20	NA
State1	Type1	20	NA
State1	Type1	2	NA

State1	Type1	7	NA
State1	Type1	30	NA
State1	Type1	0	NA
State1	Type1	40	NA
State1	Type1	40	NA
State1	Type1	2	NA
State1	Type1	40	NA
State1	Type1	1	NA
State1	Type1	3	NA
State1	Type1	2	NA
State1	Type1	2	NA

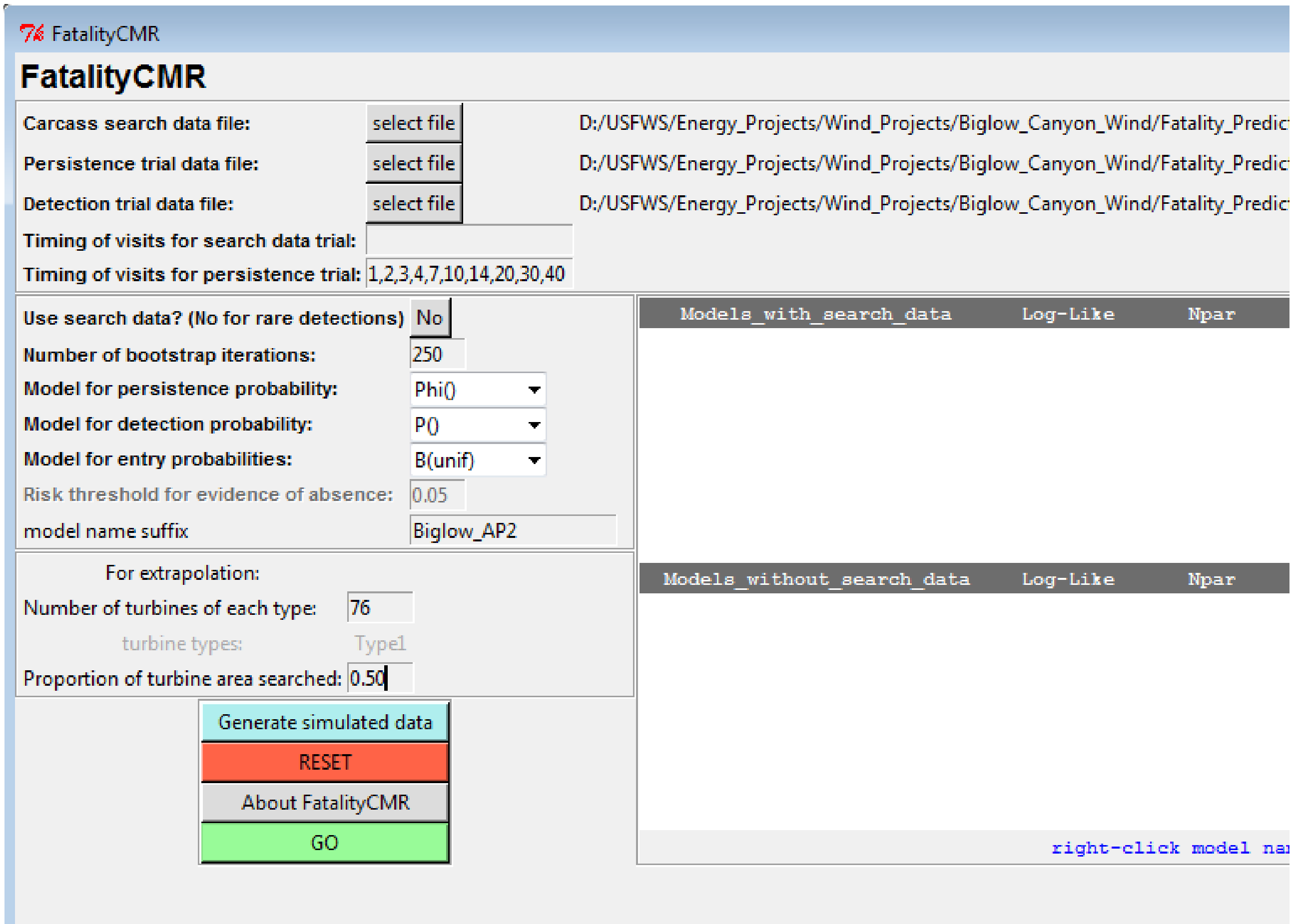
Detection Trial (i.e. Searcher Efficiency) Data

State	Type	Nd	kd
State1	Type1	93	74

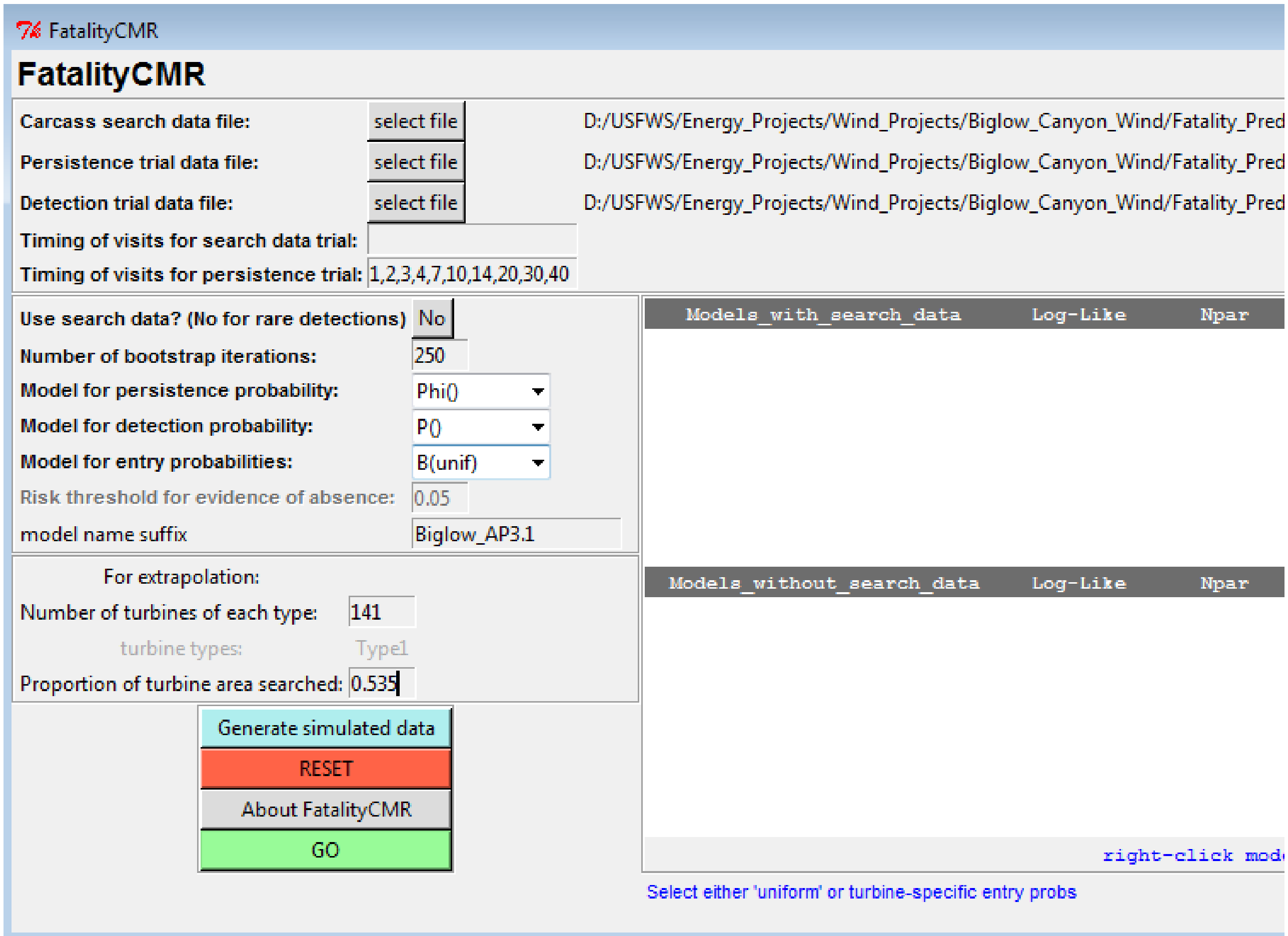
FCMR Inputs – Analysis Period #1
(Carcass Search File contains no fatalities of either species)



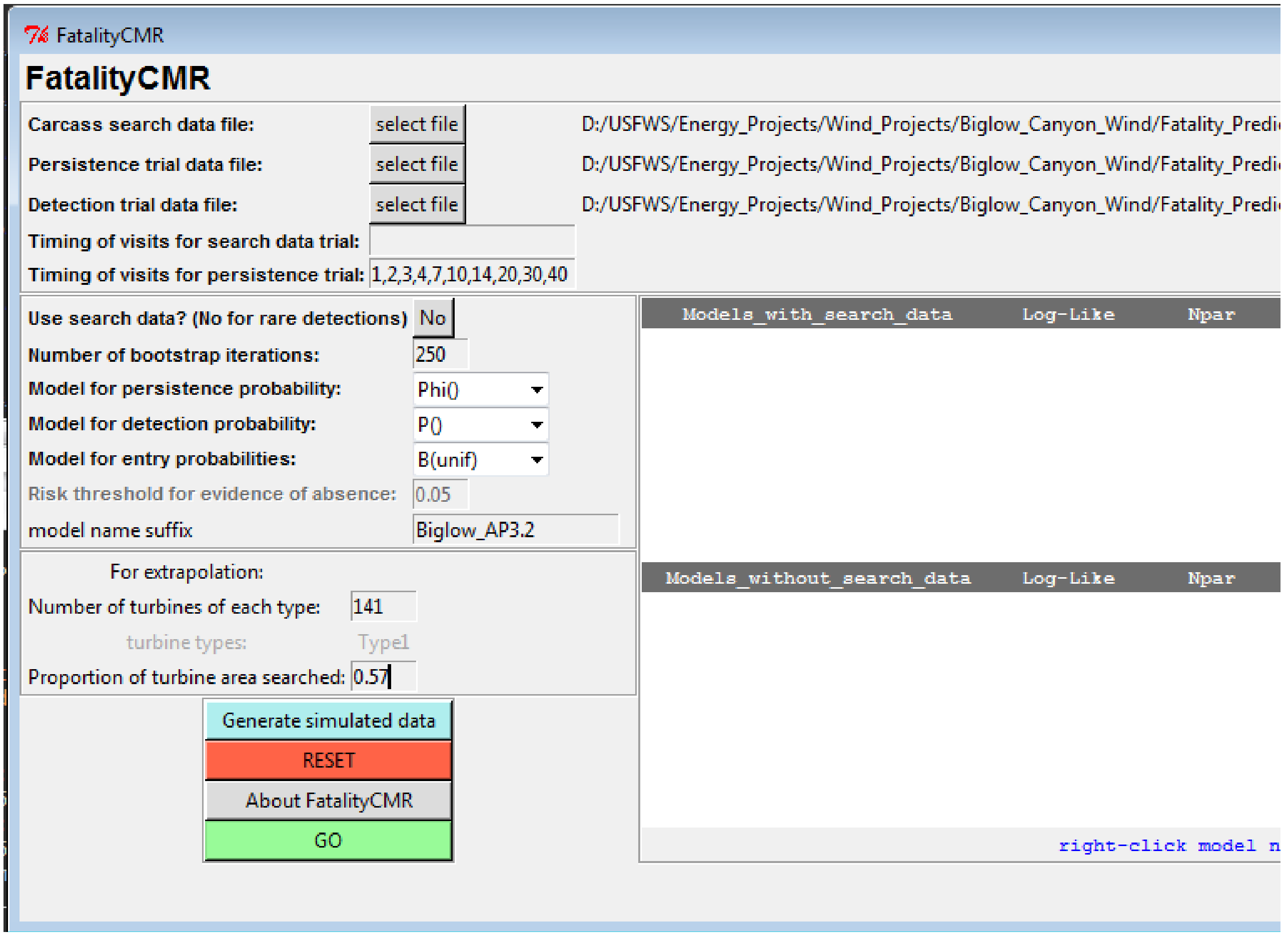
<u>FCMR Inputs – Analysis Period #2</u>
(Carcass Search File contains no fatalities of either species)



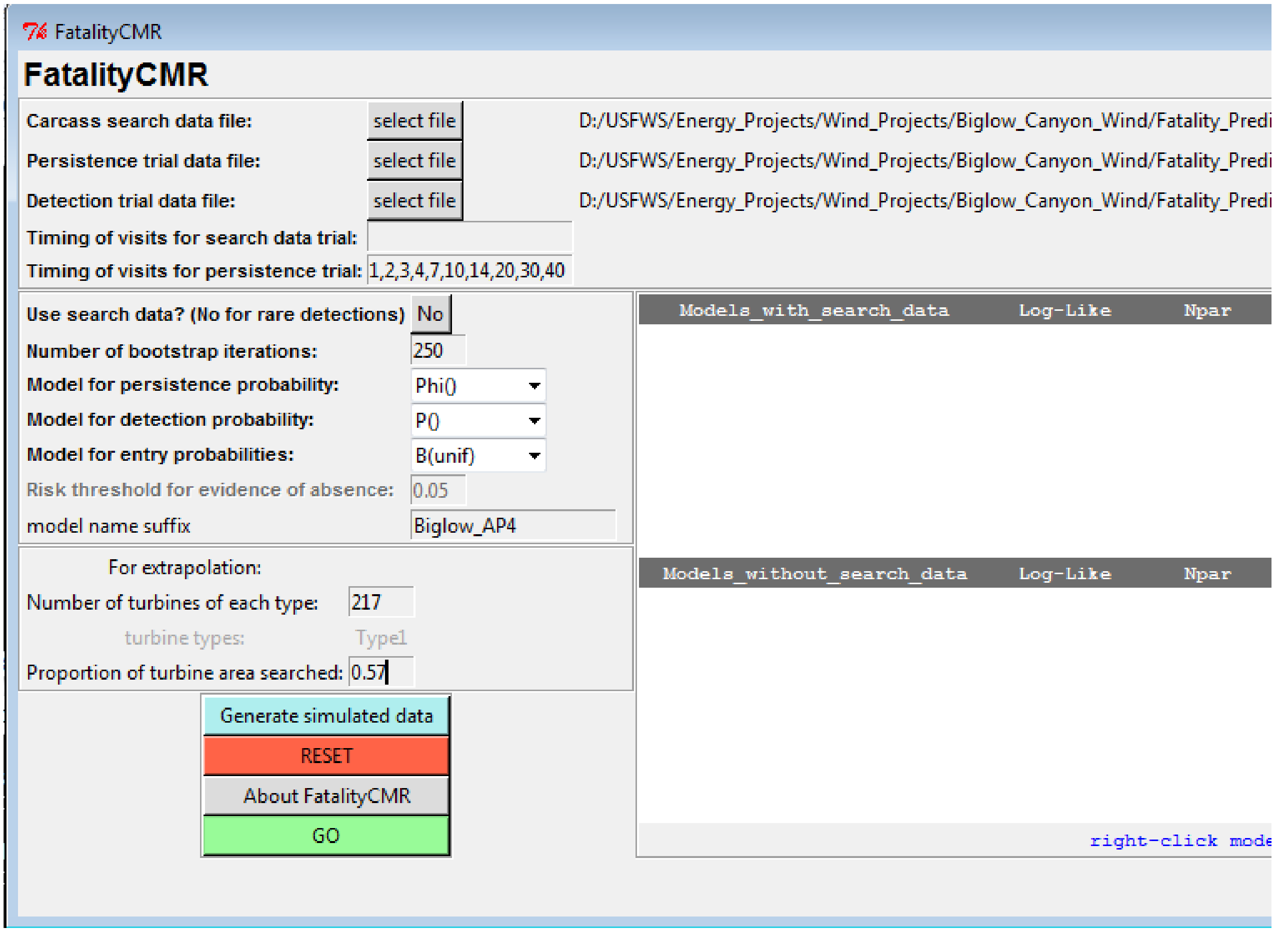
<u>FCMR Inputs – Analysis Period #3</u>
(Carcass Search File contains no fatalities of either species)



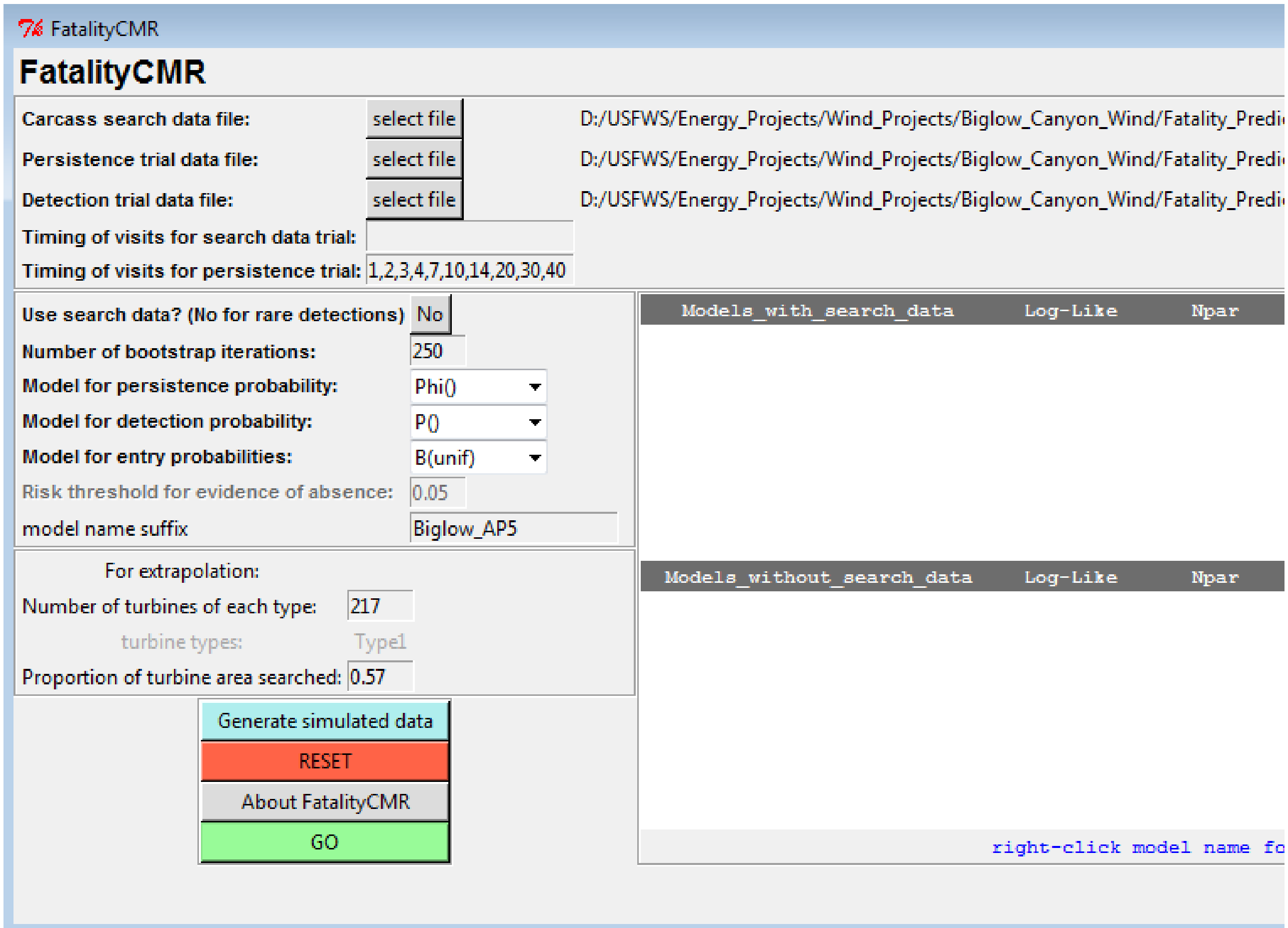
<u>FCMR Inputs – Analysis Period #4</u>
(Carcass Search File contains no fatalities of either species)



<u>FCMR Inputs – Analysis Period #5</u>
(Carcass Search File contains no fatalities of either species)



<u>FCMR Inputs – Analysis Period #6</u>
(Carcass Search File contains no fatalities of either species)


FatalityCMR
FatalityCMR
Carcass search data file:
select file
D:/USFWS/Energy_Projects/Wind_Projects/Biglow_Canyon_Wind/Fatality_Predi
Persistence trial data file:
select file
D:/USFWS/Energy_Projects/Wind_Projects/Biglow_Canyon_Wind/Fatality_Predi
Detection trial data file:
select file
D:/USFWS/Energy_Projects/Wind_Projects/Biglow_Canyon_Wind/Fatality_Predi
Timing of visits for search data trial:
Timing of visits for persistence trial: 1,2,3,4,7,10,14,20,30,40
Use search data? (No for rare detections) No
Number of bootstrap iterations: 250
Model for persistence probability: Phi()
Model for detection probability: P()
Model for entry probabilities: B(unif)
Risk threshold for evidence of absence: 0.05
model name suffix Biglow_AP5
For extrapolation:
Number of turbines of each type: 217
turbine types: Type1
Proportion of turbine area searched: 0.57
Generate simulated data
RESET
About FatalityCMR
GO
Models_with_search_data Log-Like Npar
Models_without_search_data Log-Like Npar
right-click model name fo