View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by DigitalCommons@University of Nebraska

University of Nebraska - Lincoln
DigitalCommons@University of Nebraska - Lincoln

US Fish & Wildlife Publications US Fish & Wildlife Service

2018

The utility of point count surveys to predict wildlife interactions with wind energy facilities: An example focused on golden eagles

Maitreyi Sur
Boise State University, maitreyisur@boisestate.edu

James R. Belthoff
Boise State University, jbeltho@boisestate.edu

Emily R. Bjerre
U.S. Fish and Wildlife Service, emily_bjerre@fws.gov

Brian A. Millsap
U.S. Fish and Wildlife Service, brian_a_millsap@fws.gov

Todd Katzner
U.S. Geological Survey, tkatzner@usgs.gov

Follow this and additional works at: https://digitalcommons.unl.edu/usfwspubs

Sur, Maitreyi; Belthoff, James R.; Bjerre, Emily R.; Millsap, Brian A.; and Katzner, Todd, "The utility of point count surveys to predict wildlife interactions with wind energy facilities: An example focused on golden eagles" (2018). *US Fish & Wildlife Publications*. 526.
https://digitalcommons.unl.edu/usfwspubs/526

This Article is brought to you for free and open access by the US Fish & Wildlife Service at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in US Fish & Wildlife Publications by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

Ecological Indicators 88 (2018) 126–133

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

The utility of point count surveys to predict wildlife interactions with wind energy facilities: An example focused on golden eagles

Maitreyi Sur[a,*], James R. Belthoff[a], Emily R. Bjerre[b], Brian A. Millsap[c], Todd Katzner[d]

[a] Boise State University, Department of Biological Sciences, 1910 University Drive, Boise, ID 83725, USA
[b] U.S. Fish and Wildlife Service, Division of Migratory Bird Management, PO Box 18, Haleiwa, HI 96712, USA
[c] U.S. Fish and Wildlife Service, Division of Migratory Bird Management, 2105 Osuna NE, Albuquerque, NM 87113, USA
[d] U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, 970 Lusk St., Boise, ID 83706, USA

ARTICLE INFO

Keywords:
Aquila chrysaetos
California
Golden eagle monitoring
Point count
Sampling
Wind energy

ABSTRACT

Wind energy development is rapidly expanding in North America, often accompanied by requirements to survey potential facility locations for existing wildlife. Within the USA, golden eagles (*Aquila chrysaetos*) are among the most high-profile species of birds that are at risk from wind turbines. To minimize golden eagle fatalities in areas proposed for wind development, modified point count surveys are usually conducted to estimate use by these birds. However, it is not always clear what drives variation in the relationship between on-site point count data and actual use by eagles of a wind energy project footprint. We used existing GPS-GSM telemetry data, collected at 15 min intervals from 13 golden eagles in 2012 and 2013, to explore the relationship between point count data and eagle use of an entire project footprint. To do this, we overlaid the telemetry data on hypothetical project footprints and simulated a variety of point count sampling strategies for those footprints. We compared the time an eagle was found in the sample plots with the time it was found in the project footprint using a metric we called "error due to sampling". Error due to sampling for individual eagles appeared to be influenced by interactions between the size of the project footprint (20, 40, 90 or 180 km^2) and the sampling type (random, systematic or stratified) and was greatest on 90 km^2 plots. However, use of random sampling resulted in lowest error due to sampling within intermediate sized plots. In addition sampling intensity and sampling frequency both influenced the effectiveness of point count sampling. Although our work focuses on individual eagles (not the eagle populations typically surveyed in the field), our analysis shows both the utility of simulations to identify specific influences on error and also potential improvements to sampling that consider the context-specific manner that point counts are laid out on the landscape.

1. Introduction

Monitoring and surveying are critical for wildlife management and conservation. These processes are designed to estimate wildlife occupancy, abundance and survival, and thus to evaluate existing management practices and compliance with regulatory requirements (Gibbs et al., 2013). However, wildlife monitoring is often confounded by survey error (Yoccoz et al., 2001). For example, most survey methods do not detect all animals in a surveyed area and therefore rely on subsampling and inference to larger areas. These problems are especially relevant to sparsely distributed species for whom detection rate is low and dependent on survey effort and on sampling design (Thompson, 2004).

At large infrastructure facilities, pre-construction wildlife surveys have become integral to risk assessment and conservation efforts. Wind energy development is rapidly expanding in North America. Because wildlife is sometimes negatively affected by these facilities, developers face potential conflict with legally-protected species (Kiesecker et al., 2011). The consequences to wildlife from turbine development are direct, through strike injury or mortality (Hunt, 2002; Drewitt and Langston, 2006; Kunz et al., 2007; Arnett et al., 2008; De Lucas et al., 2008) or indirect, through habitat loss, fragmentation and disturbance (Drewitt and Langston, 2006; Pruett et al., 2009; Kiesecker et al., 2011).

The U.S. Fish and Wildlife Service (USFWS) suggests modified point count surveys to assess use of existing and proposed wind facilities by some species of birds such as golden eagles (*Aquila chrysaetos*) (e.g., Strickland et al., 2011, USFWS, 2013). Point count sampling was originally developed to monitor passerines in terrestrial habitats (Ralph

---

* Corresponding author.
E-mail addresses: maitreyisur@boisestate.edu (M. Sur), jbeltho@boisestate.edu (J.R. Belthoff), emily_bjerre@fws.gov (E.R. Bjerre), brian_a_millsap@fws.gov (B.A. Millsap), tkatzner@usgs.gov (T. Katzner).

https://doi.org/10.1016/j.ecolind.2018.01.024
Received 28 November 2016; Received in revised form 11 January 2018; Accepted 13 January 2018
1470-160X/ © 2018 Elsevier Ltd. All rights reserved.

This document is a U.S. government work and is not subject to copyright in the United States.

et al., 1995). The process involves recording the number of individual birds observed or heard within a circular plot. The modified point count approach recommended by the USFWS is used to record the amount of time that eagles spend in a three-dimensional survey plot. These data are then input to an eagle risk model (New et al., 2015) to predict eagle exposure to turbines, collision probability and fatality rates for a proposed wind facility (e.g., Douglas et al., 2012). However, it is not clear how accurately the data collected during these point counts relate to actual use of the project footprint by eagles.

Golden eagles are among the most high-profile species killed at wind facilities (Katzner et al., 2012). Within the USA, golden eagles also have state and national-level regulatory protections (e.g., the Bald and Golden Eagle Protection Act, 16 U.S.C. 668 *et seq*.). Consequently, substantial effort has been dedicated to understand and mitigate threats to this species and, at wind energy facilities, detailed protocols have been designed to predict and manage disturbance and take of golden eagles (New et al., 2015; Strickland et al., 2011; USFWS, 2013). However, golden eagles are not easy to monitor. This is because many aspects of their ecology – low population density, long-distance and often seasonal movements, and avoidance of humans – all combine to make them difficult to detect and count (Fuller and Mosher, 1981). Therefore, as an initial step towards evaluating the utility of point count surveys as suggested by the USFWS, we examined GPS telemetry data from individual eagles tracked in an area well suited to wind energy development and we compared the amount of time a surveyor would have detected the eagles within a point count to the amount of time the eagles actually spent in the project footprint. The telemetry data we used were collected in the Mojave Desert of California with sufficiently short inter-fix intervals to allow us to evaluate the effects of different eagle survey strategies on estimates of actual use of project footprints (Garman et al., 2012).

2. Methods

2.1. Study area

California has some of the highest renewable energy targets in the continental USA (Department of Interior Secretarial Order 3285; Renewable Energy Action Team, 2010) and there are numerous planned and operating wind energy projects in southern California. Much of this development is guided by the Desert Renewable Energy Conservation Plan (DRECP; Fig. 1; California Executive Order S-14-08, Renewable Energy Action Team, 2010). Golden eagles are a conservation priority within the DRECP and there are an estimated 74 occupied golden eagle nesting territories on ~4.5 million hectares of public land in the Mojave and Sonoran Deserts of California (Latta and Thelander, 2013). Although golden eagle territories are sparsely distributed in this region, recent work demonstrates that these eagles use far more space than previously thought (Braham et al., 2015).

2.2. Telemetry data

Seven territorial adults and six fledgling golden eagles in the Mojave Desert were outfitted with solar powered GPS-GSM (global positioning system–global system for mobile communications) telemetry units (Cellular Tracking Technologies, Rio Grande, NJ, USA). Units weighed 80–95 g, < 3% of body weight (Braham et al., 2015) and were affixed as backpacks with Teflon ribbon harnesses (Kenward, 1985). The units collected GPS fixes every 15 min for 9 days and then at 30 s intervals every 10th day. Data from the units were then sent over GSM networks to a remote server where they were available for download. Post processing of the data involved removing data with GPS errors and 2D or low quality fixes (Horizontal dilution of Precision > 10)[1].

2.2.1. Analysis

Our 30 s data were too sparse for most of the detailed analyses we conducted and thus the majority of analyses were conducted on data collected at 15 min intervals. To standardize our data set, we subsampled the 30 s data to 15 min intervals (except for one analysis in which we compared 15 min and 30 s data, see below). We analyzed telemetry-derived GPS data of residential birds collected in two calendar years, 2012 and 2013 (Table 1) within a polygon encompassing part of the Mojave Desert. We note that constraints on sample size here are different than those required if estimating home range (Soanes et al., 2013).

2.3. Eagle survey guidelines

The USFWS Eagle Conservation Plan Guidance (ECPG), derived in part from Strickland et al. (2011), provides recommendations for surveys of golden eagles at potential wind facility locations (USFWS, 2013). These are often used when a project site has been selected but the exact layout of turbines has not yet been determined. A brief outline of the ECPG recommendations for point count surveys is provided in SI1.

2.4. Experimental design

At the time of data collection, there were no operational large-scale wind facilities within our study area. Thus, to evaluate the potential of modified point count surveys to assess individual eagle use of a hypothetical project footprint, we measured the times when the telemetered eagles passed through point count plots and project footprints that we simulated on the landscape. To do this, we first overlaid telemetry data from eagles onto the study area. We then compared the time spent by telemetered eagles within simulated point count plots to time spent in associated simulated project footprints. The process of converting our actual telemetry data to hypothetical survey data is described in the Supplementary information (SI2).

We evaluated the strength of the relationship between use of point count plots and use of project footprints with a metric we called the error due to sampling. To do this, we measured how error due to sampling was influenced by (a) the point count sampling type (the ways in which point count plot locations are distributed within the project footprint); (b) the sampling intensity (the spatial coverage of the project footprint by point count plots); (c) the size of the project footprints; and (d) seasonality (eagle movements and behavior often vary between breeding and non-breeding seasons). We also looked for interactions between these factors. Finally, for a subset of the data, we separately evaluated how error due to sampling was affected by changes in sampling frequency (i.e., if surveys were conducted weekly, bi-weekly, monthly or every 4 months).

The details of our analytical approach were as follows:

1. We simulated project footprints of 20, 40, 90 and 180 km^2 to capture a range of sizes of wind facilities (Fig. 2). A description of the size, shape and placement of footprints in the study area are provided in SI3. Information on number of birds and GPS fixes represented within each simulated project footprint is provided in the results.
2. We simulated modified fixed-radius point count plots within those footprints according to different sampling strategies (SI4 and point 5 below) and calculated the amount of time that telemetered eagles spent in the point count plots and in the simulated footprints (SI2).
3. We compared the amount of time telemetered eagles spent in point

---

[1] Further details on telemetry systems, their attachment to birds, the data they collect,

(*footnote continued*)
post-processing of those data, and the interpretation of these data and their relevance to eagle biology are available elsewhere (Lanzone et al., 2012; Duerr et al., 2015; Miller et al., 2014; Braham et al., 2015; Katzner et al., 2015).

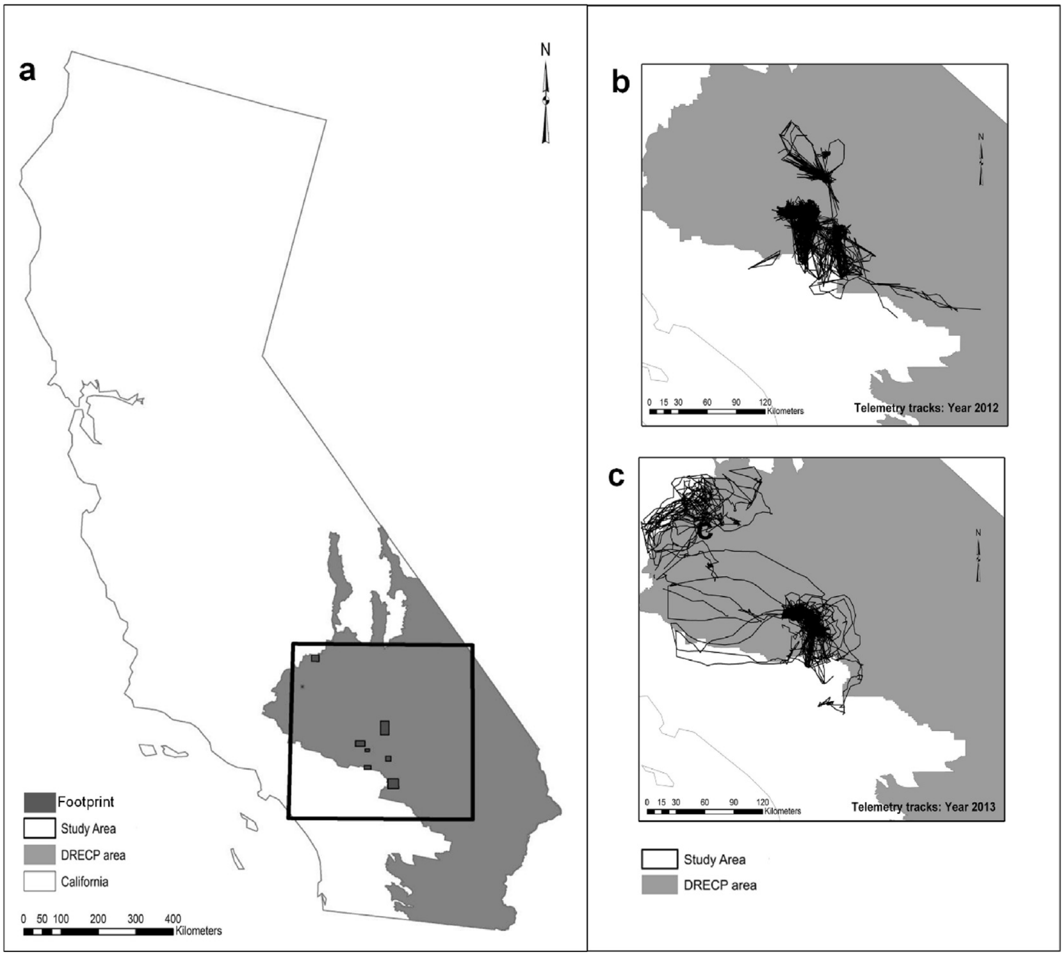


Fig. 1. (a) Map of California, USA showing locations of the DRECP, the study area (latitude 33°26′ to 36°8′N and longitude 115°23′ to 118°34′W) in which golden eagles were monitored and point counts and wind project footprints simulated. Insets show telemetry tracks of golden eagles within the boundary of the study area in years (b) 2012 and (c) 2013.

Table 1
Periods of time for which telemetry data were available for each eagle used in study of the relationship between potentially observed point count data and actual use of hypothetical wind facility project footprints (error due to sampling) by individual golden eagles in California. Ages are F (recent fledglings), 3Y (third year), A4Y (after fourth year; adult). For details on aging, see: Bloom and Clark (2001). Data were available for each bird in some years ("Y") but not in others ("N").

Bird Id	Sex	Capture Age	Data available by Year	
			2012	2013
2885	M	A4Y	Y	Y
4385	M	F	Y	N
4387	M	A4Y	Y	Y
4451	M	A4Y	Y	Y
4767	F	A4Y	Y	Y
5350	F	A4Y	Y	N
7356	M	3Y	N	Y
7546	F	3Y	Y	Y
7837	F	F	Y	N
8008	F	F	Y	N
999582	F	F	Y	N
9994161	M	F	Y	N
9994932	F	F	Y	N

count plots to the time they spent in the simulated project footprints and we evaluated the strength of the relationship between the two i.e., the "error due to sampling". To do this, we first calculated the predicted time spent in project footprints using the formula:

$$\textit{Predicted time spent in the project footprint} = \left(\frac{\textbf{\textit{actual}}\ \textit{time spent in point count plots}}{\textit{sampling intensity}\,(\%)}\right)*100 \tag{1}$$

We then used the actual time spent in the project footprint (measured by GPS telemetry) to calculate the relative error in measurement (derived from Bowerman et al., 2004) or here, an "error due to sampling", defined as follows:

$$\textit{error due to sampling} = \left|\frac{(\textbf{\textit{actual}}\ \textit{time spent in the project footprint}) - (\textbf{\textit{predicted}}\ \textit{time spent in the project footprint})}{\textbf{\textit{actual}}\ \textit{time spent in the project footprint}}\right| \tag{2}$$

4. We did this for two years of data and 24 point count approaches composed of all combinations of:
   a. three different point count sampling types (random, systematic, stratified by altitude) (SI4),
   b. two different sampling intensities (30% or 60% area coverage) (SI4),
   c. four different project footprint sizes (2 replicates each of: 20, 40, 90 and 180 km^2) (SI3 and SI4);
5. To account for seasonal changes in eagle biology and, thus, the availability of eagles to be counted, we calculated error due to sampling by season for all combinations of the sampling approaches

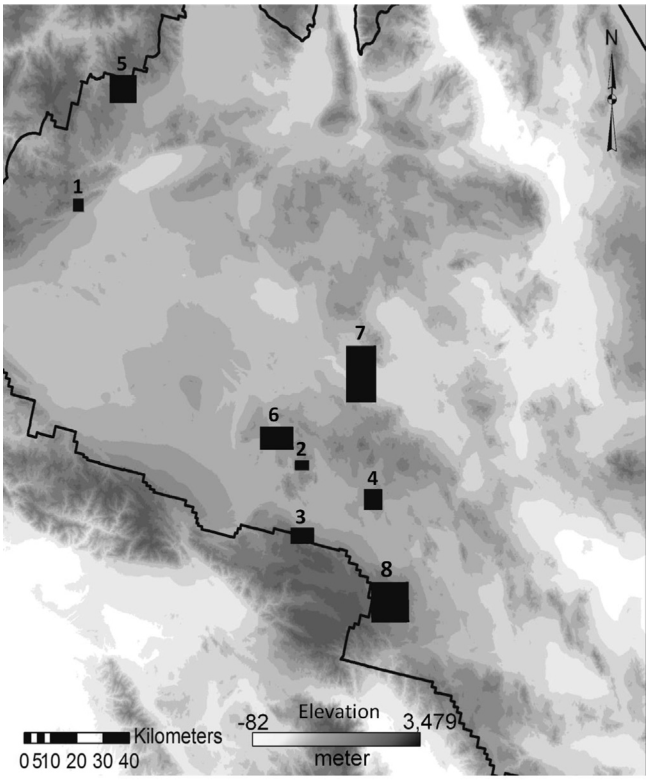


Fig. 2. Location of simulated project footprints used to evaluate effectiveness of surveys for individual golden eagles within project footprints within a pre-defined study area (see Fig. 1a) in California. Black line indicates that DRECP border, square areas are simulated project footprints of size 20 km^2 (footprint #1, #2), 40 km^2 (#3, #4), 90 km^2 (#5, #6) and 180 km^2 (#7, #8).

in point 5. We assigned seasons by dividing the calendar year into three periods we named breeding 1 (September to January, generally the time before egg-laying), breeding 2 (February to April, when eggs and chicks are in the nest) and non-breeding (May to August). These were defined based on previously published eagle movement data from this area (see Fig. 1, Braham et al. 2015).

6. To assess the potential effects of and interactions among size of the project footprint, sampling type, sampling intensity and seasons on errors due to sampling, we used a linear mixed model to evaluate fixed effects for sampling type, sampling intensity, footprint size and season (2.4.1 below).
7. We then used results from this modeling exercise in a sensitivity analysis (2.4.1 below).
8. Finally, we evaluated, for a subset of the data, the effect of sampling frequency on error due to sampling. To do this, we used a repeated measures analysis of variance to consider the effects of variation in sampling frequency from daily, to weekly, bi-weekly, monthly and every 4 months, on error due to sampling on the 20 km^2 simulated project footprints (2.4.2 below).

Data were prepared in ArcMap 10.3 (Esri, Redlands, CA, USA), and statistically analyzed with JMP Pro 12.2 (SAS Institute Inc., Cary, NC).

2.4.1. Data analysis

We evaluated if data collected at 15 min intervals were potentially biased because of the time between samples. Therefore, we tested the assumption that 15 min data reasonably represent time spent in point count plots by graphically comparing the error due to sampling from 30 s GPS data to those same 30 s data subsampled to 15 min on the 10% of days in which we collected 30 s telemetry data.

We used a linear mixed model to assess the potential effects of, and interactions among, size of project footprint, sampling type, sampling intensity, and season, on error due to sampling. To more closely approximate a normal distribution, for statistical analyses we logit transformed the values of our response variable (error due to sampling). Three of the fixed effects in our model (type, intensity, and season) were treated as repeated terms. This modeling approach considers all possible treatment combinations of interactions, including main effects (n = 4), two-way (n = 6), three way (n = 4), and four-way (n = 1) interactions. Because our design included two project footprints of each size (i.e. these were subjects), we collected two measurements for all treatment combinations (SI2).

As a form of sensitivity analysis, we evaluated changes in error due to sampling in response to variation in a single parameter. To do this, we sequentially varied sampling type, intensity and footprint size while holding all other parameters constant at each factor level.

2.4.2. Varying sampling frequency

To understand the effect of variation in sampling frequency (how often sampling is repeated) on error due to sampling, we compared error due to sampling on surveys done daily, weekly, every two weeks, monthly, and once every 4 months. Because of limitations to the number of data points for each individual, these data could not be included in the original model and this comparison was done in a separate analysis. To do this, we simulated 6 random point count plots on a 20 km^2 hypothetical project footprint and we calculated error due to sampling from those point counts. To increase the robustness of the analysis, we repeated 20 times the process of placing 6 random point count plots within the hypothetical project footprint and calculating error due to sampling. We then used a one way ANOVA to compare mean error due to sampling across the four sampling frequencies described above.

3. Results

We considered telemetry data from 13 golden eagles, including 6 males and 7 females. Twelve of those eagles (7 adults, 5 fledglings) were tracked in 2012, and 6 were tracked in 2013 (all adults that had also been tracked in 2012; Table 1). We collected 57,286 GPS data points within the study area in 2012 and 40,912 in 2013. Of these, 48,395 (84%) and 24,162 (59%), respectively, were within one of the eight project footprints. Each simulated project footprint was used by 0–6 telemetered eagles per year (Table 2). Simulated point count plots were collectively used by eagles for 0–1283 h in 2012 and 0–533 h in 2013. Simulated project footprints were used by eagles for 0–7913 h in 2012 and 1.3–5248 h in 2013.

Comparison of error due to sampling estimated from 15 min vs 30 s data suggested that by using the 15 min data we only slightly overestimate the errors due to sampling in both calendar years, 2012 and 2013 (Fig. 3). We therefore assumed that 15 min data reasonably represented time spent in point count plots and used those data for further analysis.

Error due to sampling was high and averaged 0.83 over the two years of our analyses. Because count data can either overestimate or underestimate actual use of project footprints, untransformed estimates of error due to sampling ranged from 0 to 1 (SI5 and Fig. 4). Their distribution was heavily skewed to the right with a long leftward tail (skewness = −1.68, kurtosis = 1.81) and was far from Gaussian. Transformed values were dramatically closer to normally distributed (skewness = 0.37, kurtosis = −0.42).

3.1. Effects of sampling type, sampling intensity, footprint size and seasons on error due to sampling

The only main effect that had a statistically significant effect on error due to sampling was sampling intensity. This factor was not involved in any interaction and error due to sampling decreased as sampling intensity was increased $F_{(1,132)} = 20.62, p = 0.0106$ (Table 3,

Table 2
Numeric identifier of simulated project footprints (“Number”, corresponding to those in Fig. 2), their size, number of GPS telemetry data points collected from golden eagles within each footprint (“# points”), total number (“# birds”) and identification number (“Bird ID”) of eagles in each footprint, by year. Data were used in a simulation study on the relationship between potentially observed point count data and actual use of hypothetical wind facility project footprints (error due to sampling) by eagles.

Footprint		2012			2013		
Number	Size	# points	# birds	Bird ID	# points	# birds	Bird ID
1	20 km^2	0	0	–	90	1	7356
2	20 km^2	8104	4	2885,4451,4767,8008	425	4	2885,4451,7356, 7546
3	40 km^2	98	5	4387,4451,4767,5350,8008	180	3	4451, 4767, 7546
4	40 km^2	2860	6	4161,4387,4451,5350, 7837,8008	7	1	7546
5	90 km^2	0	0	–	1366	1	7356
6	90 km^2	32,008	6	2885,4387,4451,4767,7546,8008	21,555	5	4387,4451,4767,7356,7546
7	180 km^2	4778	2	4385, 7837	43	1	7546
8	180 km^2	547	4	4451,4767,5350, 7847	496	2	4767,7546
Totals		**48,395**	**12**		**24,162**	**6**	

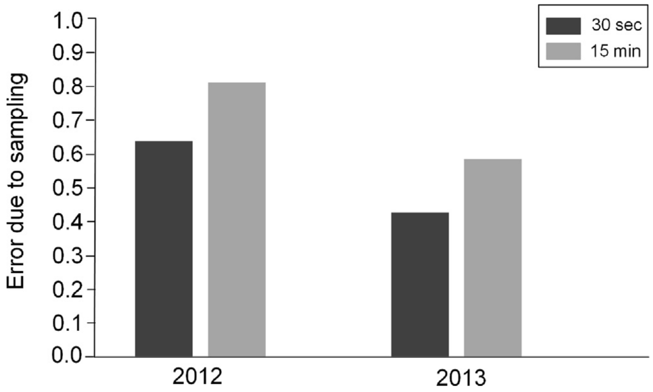


Fig. 3. Difference in the estimate of the amount of time spent within a simulated wind energy project footprint, as calculated based on GPS telemetry data collected from golden eagles in California at 30 s vs 15 min intervals. Analysis was for a single simulated project footprint of 20 km^2 in two calendar years, 2012 and 2013. Since the telemetry units collected 30 s data every 10th day, we compared hypothetical point count data inferred from the original 30 s data with those inferred from the same 30 s data subsampled to 15 min intervals. We then calculated the time spent by the eagles in the point count plots and the time spent in the entire project footprint using the 15 min and 30 s data sets and error due to sampling.

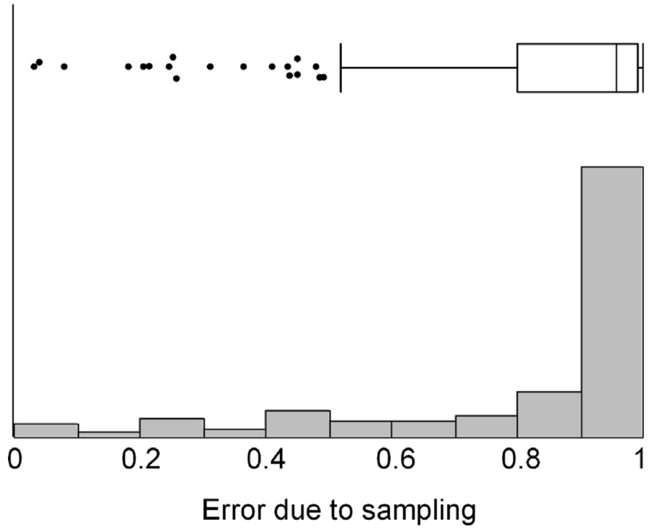


Fig. 4. Distribution of values of error due to sampling calculated across all simulation scenarios in study of the relationship between potentially observed point count data and actual use of hypothetical wind facility project footprints by telemetered golden eagles in California.

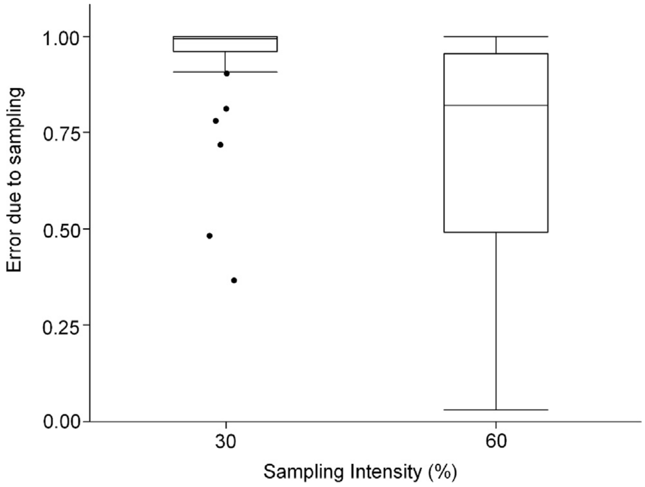


Fig. 5. Variation in the relationship between potentially observed point count data and actual use of hypothetical wind facility project footprints (error due to sampling) by telemetered golden eagles in California for two year (2012–13). Plots illustrate the actual value of error due to sampling for the main effect of sampling intensity.

Fig. 5). This implied that as the spatial coverage of the project footprint by point count plots increased, the error due to sampling decreased. There was no effect of breeding season on error due to sampling and breeding season was also not involved in any statistically significant interactions.

A term describing the interaction between two of the four fixed effects, the size of project footprint and type of sampling, also influenced error due to sampling $F_{(6,132)} = 6.57, p = 0.015$ (Table 3, Fig. 6). Predicted error due to sampling was greatest on 90 km^2 plots (Fig. 6). However, the interaction became relevant because, when sampling was random, error due to sampling decreased on both larger and smaller plots. Predicted error due to sampling also was always greater when systematic or stratified sampling was used to define point count centroids. None of the four other two-way interactions, nor any of the three-way or four-way interactions, had a statistically significant effect on error due to sampling.

3.2. *Sensitivity analysis*

Although the large error estimates made interpretation difficult, our sensitivity analysis suggested that modeled predictions appeared most responsive to sampling intensity and type and least responsive to changes in footprint size (SI6). These trends were consistent with the patterns of rankings of the F-statistics in our model (Table 3).

Table 3
Repeated measures analysis of variance assessing the relationship between potentially observed point count data and actual use of hypothetical wind facility project footprints (error due to sampling) by telemetered golden eagles in California. Simulated point count data were derived from GIS analysis of GPS-GSM telemetry data overlaid on simulated project footprints. Bold font denotes significance at the 0.05 level. # param = number of parameters in the model, DF = degrees of freedom (numerator, denominator).

Factor	# param	DF	F Ratio	Prob > F
Intensity	1	1, 3.978	20.6173	**0.0106**
Size*Type	6	6, 6.551	6.5775	**0.0151**
Type	2	2, 6.664	4.1412	0.0678
Size	3	3, 4.061	2.7252	0.1768
Type*Intensity	2	2, 7.308	1.7553	0.2385
Size*Type*Intensity	6	6, 7.159	1.6202	0.2682
Size*Seasons	6	6, 6.933	0.5431	0.7627
Size*Type*Seasons	12	12, 13.93	0.5337	0.8588
Type*Seasons	4	4, 14.04	0.4149	0.7952
Seasons	2	2, 7.036	0.3814	0.6962
Size*Type*Intensity*Seasons	12	12, 14.23	0.3722	0.9534
Type*Intensity*Seasons	4	4, 14.39	0.3512	0.8390
Size*Intensity*Seasons	6	6, 7.045	0.152	0.9824
Size*Intensity	3	3, 3.879	0.1507	0.9239
Intensity*Seasons	2	2, 7.14	0.1015	0.9048

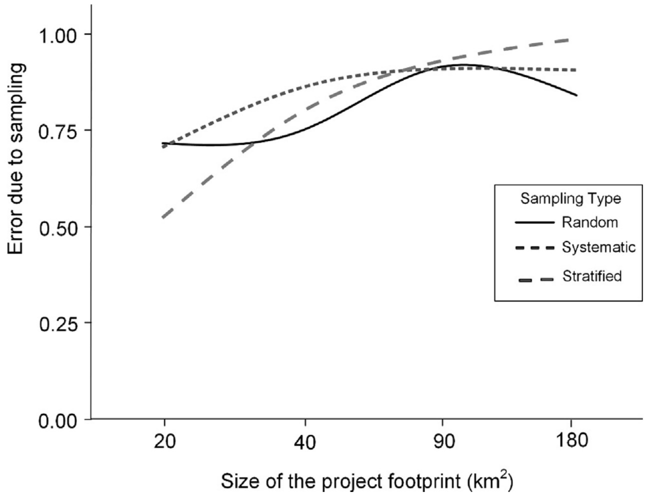


Fig. 6. Variation in the relationship between potentially observed point count data and actual use of hypothetical wind facility project footprints (error due to sampling) by telemetered golden eagles in California for two years (2012–13). Plots illustrate the value of predicted error due to sampling for two-way interactions between (a) size of the project footprint and (b) sampling type.

3.3. Effect of sampling frequency on error due to sampling

Error due to sampling responded strongly to sampling frequency and plateaued close to 1 when sampling was least frequent (Fig. 7). As we reduced the sampling frequency from measurements taken every day of the year to measurements taken weekly, bi-weekly, monthly or every 4 months, the errors due to sampling increased dramatically $F_{(4,95)} = 113.296$, $p < 0.001$.

4. Discussion

For individual telemetered eagles, our best-case results suggest that day-long point count surveys covering up to 60% of a simulated project footprint provide a poor approximation of actual golden eagle use of that footprint. Because our protocols assume that detection probability of eagles is 100%, in an actual field survey the sampling data observers collect would represent reality even less effectively. The factors that influence how these surveys perform in simulation trials provide insight into specific mechanisms that could be considered to improve survey design.

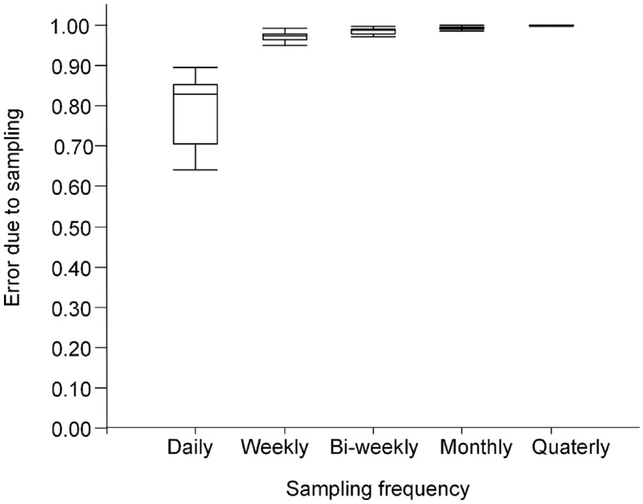


Fig. 7. Variation in the relationship between potentially observed point count data and actual use of hypothetical wind facility project footprints (error due to sampling) by telemetered golden eagles in California resulting from hypothetical point counts conducted at daily, weekly, bi-weekly, monthly or every 4 months intervals.

4.1. Survey design, eagle ecology and simulated point count results

An interaction between eagle ecology and survey design likely influenced the results of our simulated point counts. For example, we knew that these eagles left the study area at certain times of the year (Braham et al., 2015), and thus we expected, but did not find, seasonal variation in error due to sampling. This lack of an effect is likely due to the eagles' infrequent use of any particular project footprint. As a consequence, we observed dramatic within-month variation in error due to sampling that likely swamped among-season variation in this parameter.

Likewise, survey design alone also likely had a strong influence on the results of our simulated point counts. For example, although we expected that different approaches to sampling would strongly influence the error due to sampling, our results only partially support these expectations (Fig. 6). In fact, sampling type mattered inconsistently across differently sized project footprints. Similarly, because more frequent sampling usually results in more frequent detections of wildlife, we expected, and found, a relationship between sampling intensity and error due to sampling.

The biology of the telemetered eagles influenced our results at a temporal scale in a way that may further inform refinement of sampling designs for eagles. Previous analyses of this same data set (Braham et al., 2015) showed strong inter-annual differences in size of home ranges. In 2012, a large proportion of the birds in the DRECP produced chicks, as did six of our telemetered birds. In that year, home ranges were relatively smaller and birds wandered less (Braham et al., 2015). In contrast, in 2013 there was almost no successful breeding in the DRECP and the home ranges of telemetered eagles increased substantially and eagles spent more time out of the study area (Braham et al., 2015). Although we were aware of these differences, our data were too sparse to test for an effect of inter-annual variation in error due to sampling. However, given the dramatic differences in eagle behavior among the two years for which we had telemetry data, we suspect that were we able to test for it, we would have detected such an effect. Thus, if managers wish to improve design of the eagle surveys we evaluated, it may be helpful to incorporate long-term monitoring data into survey design at specific sites (e.g., a site with high inter-annual variation in eagle behavior may require more years of surveys than a site with more consistent behavior patterns).

Finally, in evaluating survey design, it is important to bear in mind that most of our calculations were based on best case scenarios in which surveys were conducted continuously throughout the year. It is therefore intuitive that as we reduced our sampling frequency to more realistic scenarios of weekly, monthly or every 4 months, the efficacy of the point counts declined significantly. Continuous monitoring is rarely possible and monitoring regimes capable of detecting trends are weakened by observational and economic constraints (Field et al., 2005). As such, the patterns we observed are likely illustrative of the difficulty in designing logistically feasible yet effective surveys for this species.

4.2. Improving point count sampling

Our statistical analyses suggest that efforts to improve eagle surveys could focus especially on sampling frequency, sampling intensity, and accounting for size of the project footprint. These factors were all reflective of the number of observations of eagles collected. Taken together they suggest that current surveys on point count plots may collect too few measurements to allow strong inference to project footprints.

For rare and sparsely-distributed species such as golden eagles, success in monitoring requires sampling designs that account for context-specific parameters such as the size and topography of the project footprint. It has been suggested that the number of point count surveys should factor in the size of the project and representative habitats at turbines (Strickland et al., 2011). An innovative approach to solving this sampling problem may be use of resource selection functions (RSF; Manly et al., 2002a) to design a stratified sampling scheme (Thompson, 2004). This technique involves creating a RSF to describe the likelihood of use of each habitat type present and then stratifying sampling to focus on habitat types that the focal species is selecting. Often this process requires a two-phase approach, with an initial survey to estimate resource selection functions that can be used in phase two to assign survey plot locations (Manly et al., 2002b)

The variation we observed in error due to sampling speaks to the need to adjust sampling to account for local eagle ecology. For example, golden eagles can show many types of seasonal movements (Watson, 2010; Watson et al., 2014; Braham et al., 2015). Although an eagle in California desert may spend all year tightly on a territory, eagles counted there may include seasonal migrants to the region and local eagles may show altitudinal or short-distance seasonal movements that influence detection rates. Adaptive sampling designs have been used to improve precision and efficiency of surveys to aid management outcomes (Thompson, 1990; Yoccoz et al., 2001). Adapting surveys for eagles to account for these movements would likely reduce error due to sampling and improve the information surveys provide.

5. Conclusions

Improving wildlife surveys to avoid or minimize potential consequences of energy infrastructure development on species can be challenging, expensive and time-consuming. Simulations can be an effective way to test the efficiency of candidate survey methods. Although our work focuses on individual eagles (not eagle populations), our analysis shows the utility of simulations as a potential mechanism to improve surveys at wind energy facilities by considering the context-specific way point counts are laid out on the landscape. Our work demonstrates not only the problems associated with sampling for species such as golden eagles, but also that the effectiveness of point count sampling at wind facilities is strongly dependent on the size of the wind facilities, the type of sampling undertaken and the degree to which point count plots cover the area of the project footprint. Continued evaluation and improvement of monitoring efforts could proceed further using empirical data, incorporating meteorological and topographic information to better understand eagle flight, or running simulations in an iterative framework such as we present here. Such future efforts should also explore how these results, based on sampling of individuals, relate to use of the project footprint by eagle populations more broadly.

Acknowledgments

Telemetry data collection was funded by Bureau of Land Management grant agreement L11PX02237; this analysis of those data was supported by U.S. Fish and Wildlife Service through an interagency agreement with the U.S. Geological Survey (#4500069170). Statement of author contributions: the USFWS Eagle Technical Assessment Team developed the concept for this study, all authors contributed to study design, MS, TK and JB designed the statistical analyses and MS and JB carried out those analyses, MS and TK led writing of the manuscript, all authors revised the manuscript. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2018.01.024.

References

Arnett, E.B., Brown, W.K., Erickson, W.P., Fiedler, J.K., Hamilton, B.L., Henry, T.H., Jain, A., Johnson, G.D., Kerns, J., Koford, R.R., Nicholson, C.P., O'Connell, T.J., Piorkowski, M.D., Tankersley, R.D., 2008. Patterns of bat fatalities at wind energy facilities in North America. J. Wildl. Manage. 72, 61–78.

Bloom, P.H., Clark, W.S., 2001. Molt and sequence of plumages of golden eagles and a technique for inhand ageing. N. Am. Bird Bander 26, 97–116.

Bowerman, B., O'Connell, R., Koehler, A., 2004. Forecasting: Methods and Applications. Thompson Brooks/Cole, Belmont, CA.

Braham, M., Miller, T., Duerr, A.E., Lanzone, M., Fesnock, A., LaPre, L., Driscoll, D., Katzner, T., 2015. Home in the heat: dramatic seasonal variation in home range of desert golden eagles informs management for renewable energy development. Biol. Conserv. 186, 225–232.

De Lucas, M., Janss, G.F.E., Whitfield, D.P., Ferrer, M., 2008. Collision fatality of raptors in wind farms does not depend on raptor abundance. J. Appl. Ecol. 45, 1695–1703.

Douglas, D.J., Follestad, A., Langston, R.H., Pearce-Higgins, J.W., 2012. Modelled sensitivity of avian collision rate at wind turbines varies with number of hours of flight activity input data. Ibis 154, 858–861.

Draft Desert Renewable Energy Conservation Plan and EIR/EIS, 2014. Renewable Energy Action Team, CA, USA.

Drewitt, A.L., Langston, R.H., 2006. Assessing the impacts of wind farms on birds. Ibis 148, 29–42.

Duerr, A.E., Miller, T.A., Lanzone, M., Brandes, D., Cooper, J., O'Malley, K., Katzner, T., 2015. Flight response of slope-soaring birds to seasonal variation in thermal generation. Funct. Ecol. 29, 779–790.

Field, S.A., Tyre, A.J., Possingham, H.P., 2005. Optimizing allocation of monitoring effort under economic and observational constraints. J. Wildl. Manage. 69, 473–482.

Fuller, M.R., Mosher, J.A., 1981. Methods of detecting and counting raptors: a review. Stud. Avian Biol. 6, 264.

Garman, S.L., Schweiger, E.W., Manier, D.J., 2012. Simulating future uncertainty to guide the selection of survey designs for long-term monitoring. In: Gitzen, R.A., Millspaugh, J.J., Cooper, A.B., Licht, D.S. (Eds.), Design and Analysis of Long-term Ecological Monitoring Studies. Camibridge University Press, pp. 228–250.

Gibbs, J.P., Snell, H.L., Causton, C.E., 2013. Wildlife for adaptive effective monitoring: lessons from the Galapagos Islands management. J. Wildl. Manage. 63, 1055–1065.

Hunt, G., 2002. Golden Eagles in a Perilous Landscape: Predicting the Effects of Mitigation for Wind Turbine Blade-Strike Mortality. California Energy Commission Consultant Report.

Katzner, T.E., Brandes, D., Miller, T., Lanzone, M., Maisonneuve, C., Tremblay, J.A., Mulvihill, R., Merovich, G.T., 2012. Topography drives migratory flight altitude of golden eagles: implications for on-shore wind energy development. J. Appl. Ecol. 49, 1178–1186.

Katzner, T.E., Turk, P.J., Duerr, A.E., Miller, T.A., Lanzone, M.J., Cooper, J.L., Lemaître, J., 2015. Use of multiple modes of flight subsidy by a soaring terrestrial bird, the golden eagle Aquila chrysaetos, when on migration. J. R. Soc. Interface 12, 20150530.

Kenward, R.E., 1985. Raptor radio-tracking and telemetry. ICBP Tech. Publ. 5, 409–420.

Kiesecker, J.M., Evans, J.S., Fargione, J., Doherty, K., Foresman, K.R., Kunz, T.H., Naugle, D., Nibbelink, N.P., Niemuth, N.D., 2011. Win-win for wind and wildlife: a vision to facilitate sustainable development. PLoS One 6, 1–8.

Kunz, T.H., Arnett, E.B., Erickson, W.P., Hoar, A.R., Johnson, G.D., Larkin, R.P., Strickland, M.D., Thresher, R.W., Tuttle, M.D., 2007. Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. Front. Ecol. Environ. 5, 315–324.

Lanzone, M.J., Miller, T.A., Turk, P., Brandes, D., Halverson, C., Maisonneuve, C., Tremblay, J., Cooper, J., O'Malley, K., Brooks, R.P., Katzner, T., 2012. Flight responses by a migratory soaring raptor to changing meteorological conditions. Biol. Lett. 8, 710–713.

Latta, B., Thelander, C., 2013. Results of 2012 Golden Eagle Nesting Surveys of the California Desert and Northern California Districts. Final Rep. BioResource Consultants Inc., Ojai, CA.

Manly, B.F., McDonald, L., Thomas, D., McDonald, T., Erickson, W., 2002a. Resource Selection by Animals: Statistical Design and Analysis for Field Studies, Second edition. Kluwer Press, New York, New York, USA.

Manly, B.F., Akroyd, J.A.M., Walshe, K.A., 2002b. Two-phase stratified random surveys on multiple populations at multiple locations. N. Z. J. Mar. Freshwater Res. 36, 581–591.

Miller, T.A., Brooks, R.P., Lanzone, M., Brandes, D., Cooper, J., O'Malley, K., Maisonneuve, C., Tremblay, J., Duerr, A., Katzner, T., 2014. Assessing risk to birds from industrial wind energy development via paired resource selection models. Conserv. Biol. 28, 745–755.

New, L., Bjerre, E., Millsap, B., Otto, M.C., Runge, M.C., 2015. A collision risk model to predict avian fatalities at wind facilities: an example using Golden Eagle, Aquila chrysaetos. PloS One 10, e0130978.

Pruett, C.L., Patten, M.A., Wolfe, D.H., 2009. It's not easy being green: wind energy and a declining grassland bird. Bioscience 59, 257–262.

Ralph, C.J., Sauer, J.R., Droege, S., 1995. Monitoring Bird Populations by Point Counts. Gen. Tech. Rep. PSW-GTR-149. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA, pp. 187.

Soanes, L.M., Arnould, J.P., Dodd, S.G., Sumner, M.D., Green, J.A., 2013. How many seabirds do we need to track to define home-range area? J. Appl. Ecol. 50, 671–679.

Strickland, M.D., Arnett, E.B., Erickson, W.P., Johnson, D.H., Johnson, G.D., Morrison, M.L., Shaffer, J.A., Warren-Hicks, W., 2011. Comprehensive Guide to Studying Wind Energy/Wildlife Interactions. Prepared for the National Wind Coordinating Collaborative, Washington, D.C., USA.

Thompson, S.K., 1990. Adaptive cluster sampling. J. Am. Stat. Assoc. 85, 1050–1059.

Thompson, W., 2004. Sampling Rare or Elusive Species: Concepts, Designs, and Techniques for Estimating Population Parameters. Island Press, Washington, DC.

USFWS, 2013. Eagle Conservation Plan Guidance Module 1 – Land-Based Wind Energy. Version 2. U.S. Fish and Wildlife Service.

Watson, J., 2010. The Golden Eagle, Second edition. T&AD Poyser, London.

Watson, J.W., Duff, A.A., Davies, R.W., 2014. Home range and resource selection by gps-monitored adult golden eagles in the Columbia plateau ecoregion: implications for wind power development. J. Wildl. Manage. 78, 1012–1021.

Yoccoz, N.G., Nichols, J.D., Boulinier, T., 2001. Monitoring of biological diversity in space and time. Trends Ecol. Evol. 16, 446–453.

SI1: The US Fish and Wildlife Eagle Conservation Plan Guidance (ECPG) provides specific recommendations for point count surveys of golden eagles to assess use of existing and proposed wind facilities (e.g. Strickland et al. 2011, USFWS 2013). These can be summarized as follows:

- point counts carried out from the center of a fixed 800 m radius plot (~2 km^2);
- plots located either randomly, systematically or in a stratified manner within the project footprint (we refer to these as "sampling types");
- point count centroids at vantage points to maximize visibility of eagles;
- plots laid out such that there is ≥30% spatial coverage of the project footprint (we refer to spatial coverage as the "sampling intensity");
- recording the number of eagles observed and the number of minutes they were in flight within the plot;
- conducting point counts for 1, 2 or more hrs.

Beyond ensuring a minimum of 30% coverage of a facility, the Eagle Conservation Plan makes only general recommendations about adjusting sampling effort based on the size of the wind facility.

SI2: Converting telemetry data to hypothetical survey data.

To convert our telemetry data to hypothetical survey data, we simulated modified point count plots within project footprints. Locations for point count stations were selected based on the different sampling approaches (SI3). We then used telemetry data from the 13 instrumented golden eagles to calculate the time spent by each bird in 800m plots centered on those stations. These data differ from those collected during a true eagle point count because a true count would include observations from all eagles detected, regardless of whether or not they were telemetered. Our data only include observations from our telemetered birds and other non-telemetered eagles may have been present at the same time.

We assumed that birds entered the sampling plot at the time of the first fix located within the plot and that they left at the time of the first subsequent fix located outside the plot; that is, we did not try to interpolate time or distance between points. Because we used GPS fixes as a proxy for human observations, our analysis also simplifies the reality of sampling by assuming that all possible observations of individual animals are recorded and that detection probability is 100%.

We calculated the total time spent by the birds in the point count plots and the time spent in the project footprint as if a counter was present all day every day, all year (i.e., conducting continuous surveys). We assume that estimates of error due to sampling generated by continuous sampling are best-case scenarios as compared to shorter surveys that would normally be conducted during point count sampling.

SI3: Details of size, shape and placement of simulated wind facility project footprints used to evaluate effectiveness of surveys for individual golden eagles within a pre-defined study area (see Fig. 1a) in California.

We simulated project footprints of 20, 40, 90 and 180 km^2 to capture a range of sizes of wind facilities (Fig. 2). There were no consistent patterns that we could find in the shape of existing project footprints and so we simulated only rectangular project footprints. This simplified our analyses by assuming that estimation of eagle use of an area would not be influenced by the shape of the project footprint.

We randomly selected potential locations for placement of the footprints within our study area. We retained potential footprints if they contained >50 GPS telemetry fixes from eagles for at least one of the two years of the study. If the potential footprint contained ≤50 fixes, we discarded that location and we randomly selected a new location for the project footprint. We iteratively repeated this process until all footprints were assigned non-overlapping positions on the landscape (Fig. 2).

SI4: Details of factors used in the multifactorial analysis of variance to assess the potential effects of and interactions among size of the project footprint, sampling type, sampling intensity and seasons on errors due to sampling.

Sampling types

The ways in which point count plots are distributed within the simulated project footprints are defined by the sampling type, which could be either simple random, systematic or stratified. In all cases, the number of point count centroids was determined by the sampling intensity (below) and the point count plots never overlapped.

Randomly located point count centroids were placed randomly within the project footprint. Systematically located point count centroids were placed at the center of equally sized rectangular grid cells whose number was determined by the sampling intensity. Stratified point count centroids were placed randomly within the highest 40% of elevations in the plot, as defined by a 30 m Digital Elevation Model (GMTED2010, Danielson and Gesch 2011).

Sampling intensity

The degree to which point count plots cover the area of the project footprint is defined by the sampling intensity. We simulated two different sampling intensities, 30% (that suggested as a minimum by USFWS) and 60%. To cover 30% of an area of a project footprint of size 20 km^2, the total area covered by point count plots would be 6 km^2. Thus, a 20 km^2 project footprint requires three 2-km^2 point count plots for 30% coverage and six plots for 60% coverage.

Size of project footprint

We defined four different project footprint sizes (20, 40, 90 and 180 km^2), as described in SI2.

SI5: Raw data used in study of the relationship between potentially observed point count data and actual use of hypothetical wind facility project footprints (error due to sampling) by telemetered golden eagles in California. Data include error due to sampling and logit transformed valued of error due to sampling for different sampling strategies due to variations in size of the project footprint, sampling type, sampling intensity and seasons. Because our design included two project footprints of each size (i.e. these were subjects), we collected two measurements for all treatment combinations.

Size of project footprint	Sampling Type	Sampling Intensity	Seasons	Subject	Error due to sampling	Logit transformed error due to sampling
20	1	30	Breeding 1	1	.	.
20	1	60	Breeding 1	1	.	.
20	2	30	Breeding 1	1	.	.
20	2	60	Breeding 1	1	.	.
20	3	30	Breeding 1	1	.	.
20	3	60	Breeding 1	1	.	.
20	1	30	Breeding 2	1	.	.
20	1	60	Breeding 2	1	.	.
20	2	30	Breeding 2	1	.	.
20	2	60	Breeding 2	1	.	.
20	3	30	Breeding 2	1	.	.
20	3	60	Breeding 2	1	.	.
20	1	30	Non-breeding	1	0.91071806	2.322434
20	1	60	Non-breeding	1	0.518559	0.07427
20	2	30	Non-breeding	1	0.95039305	2.952745
20	2	60	Non-breeding	1	0.18193441	-1.5033
20	3	30	Non-breeding	1	0.93543128	2.673278
20	3	60	Non-breeding	1	0.2055228	-1.35213
20	1	30	Breeding 1	2	0.97797151	3.793144
20	1	60	Breeding 1	2	0.4108278	-0.36054
20	2	30	Breeding 1	2	0.9873891	4.360502
20	2	60	Breeding 1	2	0.43558968	-0.25908
20	3	30	Breeding 1	2	0.90873938	2.298339
20	3	60	Breeding 1	2	0.0397955	-3.18339
20	1	30	Breeding 2	2	0.96156124	3.219492
20	1	60	Breeding 2	2	0.4385707	-0.24696
20	2	30	Breeding 2	2	0.97554397	3.686118

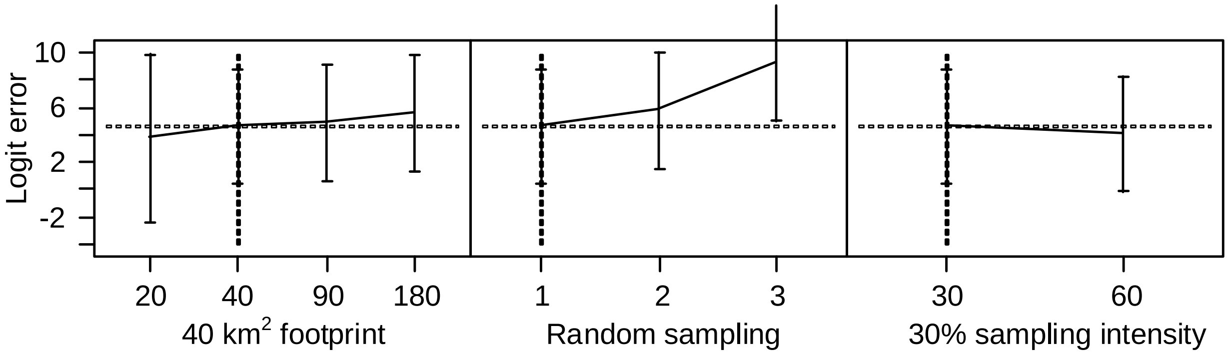
20	2	60	Breeding 2	2	0.48649795	-0.05402
20	3	30	Breeding 2	2	0.92706294	2.542425
20	3	60	Breeding 2	2	0.2148404	-1.29599
20	1	30	Non-breeding	2	0.98695756	4.326418
20	1	60	Non-breeding	2	0.5249611	0.099928
20	2	30	Non-breeding	2	0.99125285	4.730242
20	2	60	Non-breeding	2	0.62527116	0.511983
20	3	30	Non-breeding	2	0.90783667	2.287502
20	3	60	Non-breeding	2	0.03173281	-3.41816
40	1	30	Breeding 1	3	0.93722093	2.703297
40	1	60	Breeding 1	3	0.24665118	-1.11655
40	2	30	Breeding 1	3	0.91630226	2.393134
40	2	60	Breeding 1	3	0.66622385	0.691155
40	3	30	Breeding 1	3	0.99	4.59512
40	3	60	Breeding 1	3	0.25273996	-1.08405
40	1	30	Breeding 2	3	0.77868617	1.258026
40	1	60	Breeding 2	3	0.25837459	-1.05443
40	2	30	Breeding 2	3	0.99	4.59512
40	2	60	Breeding 2	3	0.49292829	-0.02829
40	3	30	Breeding 2	3	0.99	4.59512
40	3	60	Breeding 2	3	0.31222676	-0.78973
40	1	30	Non-breeding	3	0.96294511	3.257596
40	1	60	Non-breeding	3	0.6180455	0.481261
40	2	30	Non-breeding	3	0.95789655	3.12461
40	2	60	Non-breeding	3	0.81552056	1.486289
40	3	30	Non-breeding	3	0.99618897	5.566036
40	3	60	Non-breeding	3	0.60271244	0.41678
40	1	30	Breeding 1	4	0.99851309	6.509568
40	1	60	Breeding 1	4	0.99	4.59512
40	2	30	Breeding 1	4	0.99	4.59512
40	2	60	Breeding 1	4	0.99	4.59512
40	3	30	Breeding 1	4	0.99	4.59512
40	3	60	Breeding 1	4	0.99	4.59512
40	1	30	Breeding 2	4	0.7165711	0.927516
40	1	60	Breeding 2	4	0.45115258	-0.19601
40	2	30	Breeding 2	4	0.4806684	-0.07737
40	2	60	Breeding 2	4	0.99	4.59512
40	3	30	Breeding 2	4	0.99	4.59512
40	3	60	Breeding 2	4	0.45115258	-0.19601
40	1	30	Non-breeding	4	0.99911669	7.030952
40	1	60	Non-breeding	4	0.95376338	3.026643
40	2	30	Non-breeding	4	0.99837254	6.419104
40	2	60	Non-breeding	4	0.98494219	4.180686
40	3	30	Non-breeding	4	0.99669245	5.708235
40	3	60	Non-breeding	4	0.93987922	2.749396

90	1	30	Breeding 1	5	0.99071745	4.670293
90	1	60	Breeding 1	5	0.74303363	1.061796
90	2	30	Breeding 1	5	0.99005112	4.600297
90	2	60	Breeding 1	5	0.86692578	1.874046
90	3	30	Breeding 1	5	0.99279045	4.925113
90	3	60	Breeding 1	5	0.83953575	1.654778
90	1	30	Breeding 2	5	0.99	4.59512
90	1	60	Breeding 2	5	0.58778253	0.354806
90	2	30	Breeding 2	5	0.93174906	2.613872
90	2	60	Breeding 2	5	0.91700169	2.402289
90	3	30	Breeding 2	5	0.90136697	2.212506
90	3	60	Breeding 2	5	0.96120557	3.209912
90	1	30	Non-breeding	5	0.99897787	6.884843
90	1	60	Non-breeding	5	0.8507355	1.740381
90	2	30	Non-breeding	5	0.99348799	5.027573
90	2	60	Non-breeding	5	0.83889153	1.650004
90	3	30	Non-breeding	5	0.99	4.59512
90	3	60	Non-breeding	5	0.84381167	1.686867
90	1	30	Breeding 1	6	0.99364224	5.051701
90	1	60	Breeding 1	6	0.93138029	2.608088
90	2	30	Breeding 1	6	0.99403948	5.116619
90	2	60	Breeding 1	6	0.81602505	1.489645
90	3	30	Breeding 1	6	0.99182982	4.79906
90	3	60	Breeding 1	6	0.87181606	1.917112
90	1	30	Breeding 2	6	0.99666771	5.700758
90	1	60	Breeding 2	6	0.94497051	2.843285
90	2	30	Breeding 2	6	0.99711362	5.844861
90	2	60	Breeding 2	6	0.81027377	1.45179
90	3	30	Breeding 2	6	0.99775807	6.098173
90	3	60	Breeding 2	6	0.8266449	1.562033
90	1	30	Non-breeding	6	0.98938157	4.534489
90	1	60	Non-breeding	6	0.95630735	3.085899
90	2	30	Non-breeding	6	0.98942553	4.538682
90	2	60	Non-breeding	6	0.74383151	1.065979
90	3	30	Non-breeding	6	0.99551938	5.403503
90	3	60	Non-breeding	6	0.89528709	2.145922
180	1	30	Breeding 1	7	0.99463207	5.221931
180	1	60	Breeding 1	7	0.97090268	3.50758
180	2	30	Breeding 1	7	0.99860234	6.571554
180	2	60	Breeding 1	7	0.7972555	1.369229
180	3	30	Breeding 1	7	0.99977767	8.411125
180	3	60	Breeding 1	7	0.87088812	1.908834
180	1	30	Breeding 2	7	0.8101016	1.45067
180	1	60	Breeding 2	7	0.73432519	1.016679
180	2	30	Breeding 2	7	0.365356	-0.55219

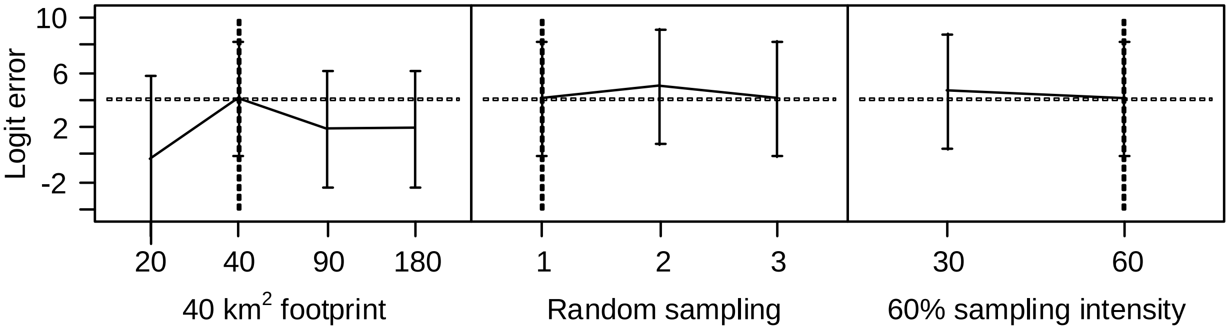
180	2	60	Breeding 2	7	0.99	4.59512
180	3	30	Breeding 2	7	0.99	4.59512
180	3	60	Breeding 2	7	0.99	4.59512
180	1	30	Non-breeding	7	0.99932797	7.304535
180	1	60	Non-breeding	7	0.95746462	3.113953
180	2	30	Non-breeding	7	0.99828288	6.365386
180	2	60	Non-breeding	7	0.81492413	1.482329
180	3	30	Non-breeding	7	0.99456785	5.209974
180	3	60	Non-breeding	7	0.9793707	3.860198
180	1	30	Breeding 1	8	0.99722869	5.88566
180	1	60	Breeding 1	8	0.5662343	0.266504
180	2	30	Breeding 1	8	0.99	4.59512
180	2	60	Breeding 1	8	0.99	4.59512
180	3	30	Breeding 1	8	0.99	4.59512
180	3	60	Breeding 1	8	0.99	4.59512
180	1	30	Breeding 2	8	0.99	4.59512
180	1	60	Breeding 2	8	0.95053424	2.955743
180	2	30	Breeding 2	8	0.99	4.59512
180	2	60	Breeding 2	8	0.93268263	2.628647
180	3	30	Breeding 2	8	0.99	4.59512
180	3	60	Breeding 2	8	0.98479276	4.17066
180	1	30	Non-breeding	8	0.99391431	5.095711
180	1	60	Non-breeding	8	0.07955021	-2.44847
180	2	30	Non-breeding	8	0.99671856	5.716186
180	2	60	Non-breeding	8	0.95096205	2.96488
180	3	30	Non-breeding	8	0.99863042	6.591881
180	3	60	Non-breeding	8	0.99677453	5.733445

SI6: Sensitivity analysis, done using the “Profiler” feature in JMP, to determine the effect of variation in model parameters on response variables for a study of the relationship between potentially observed point count data and actual use of hypothetical wind facility project footprints (error due to sampling) by telemetered golden eagles in California. Plots show changes in model prediction with variation of (a,b) sampling intensity; (c,d,e) size of the project footprint; and (f,g,h,i) sampling type against the logit transformed error due to sampling (“Logit Error”). Horizontal black lines show mean logit error at a particular set of baseline conditions identified by the vertical black lines. For example, in (a), baseline conditions are 30% intensity, 40km^2 plot, and random sampling. Plotted points show the mean and 95% confidence interval when the other two parameters (in this case footprint size and sampling type) are varied.

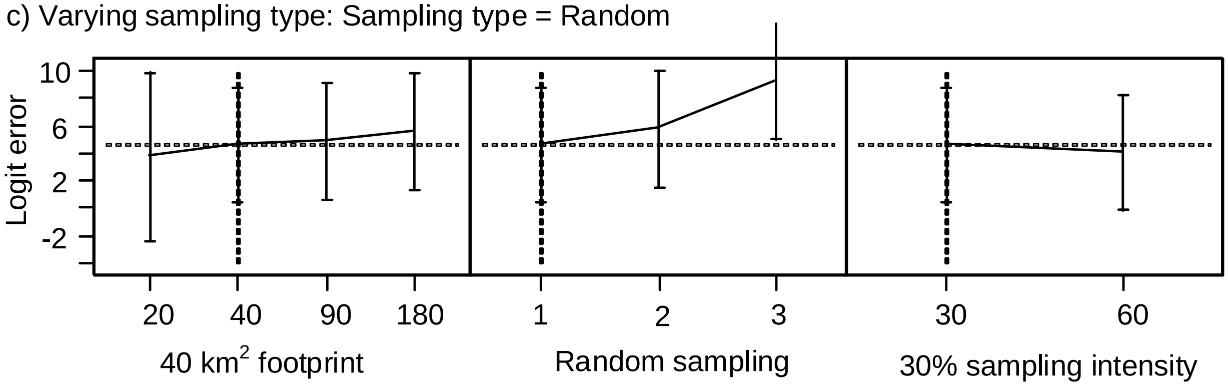
a) Varying sampling intensity: Intensity = 30%



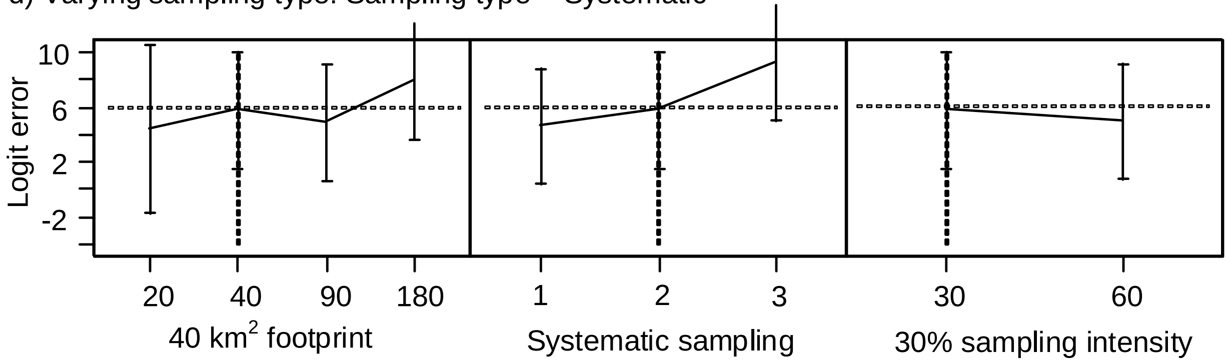
b) Varying sampling intensity: Intensity = 60%



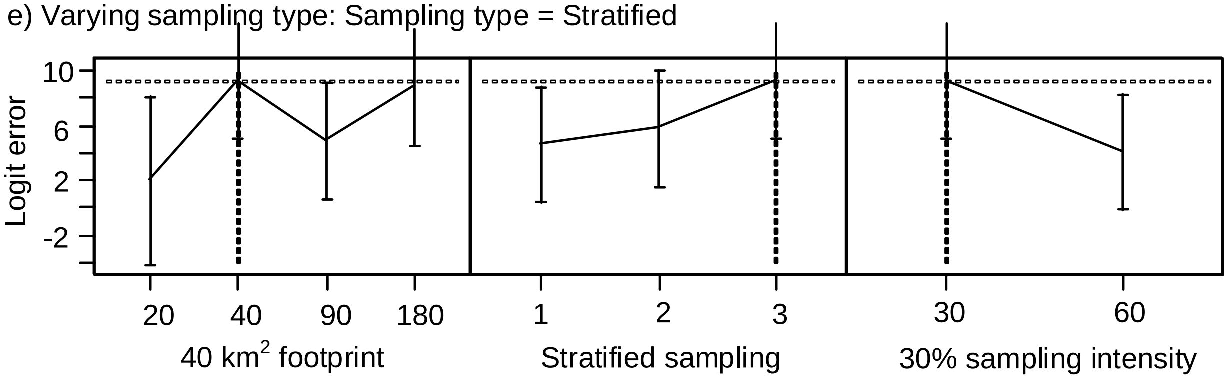
c) Varying sampling type: Sampling type = Random



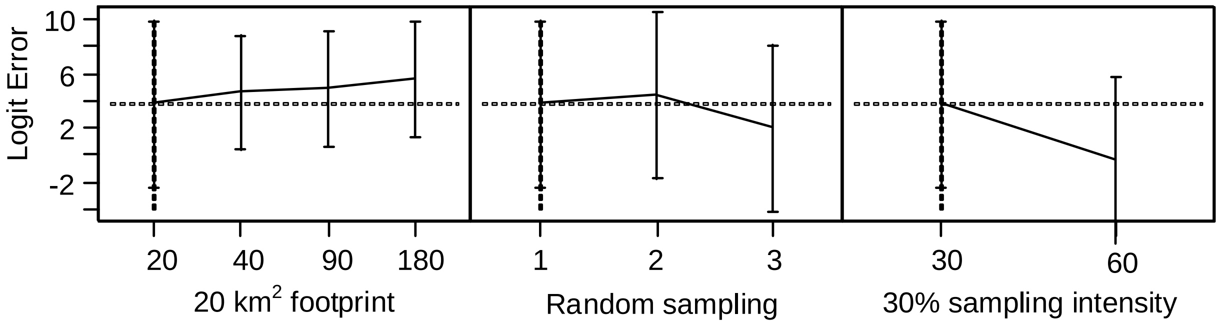
d) Varying sampling type: Sampling type = Systematic



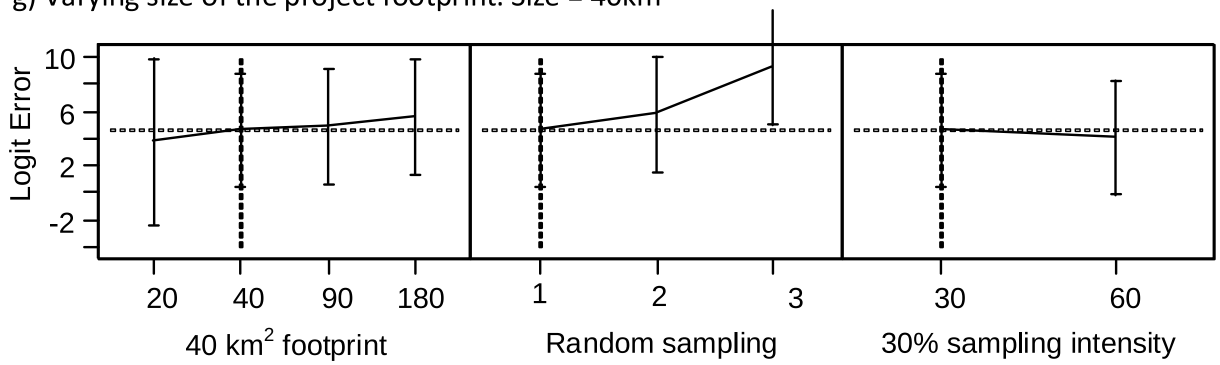
e) Varying sampling type: Sampling type = Stratified



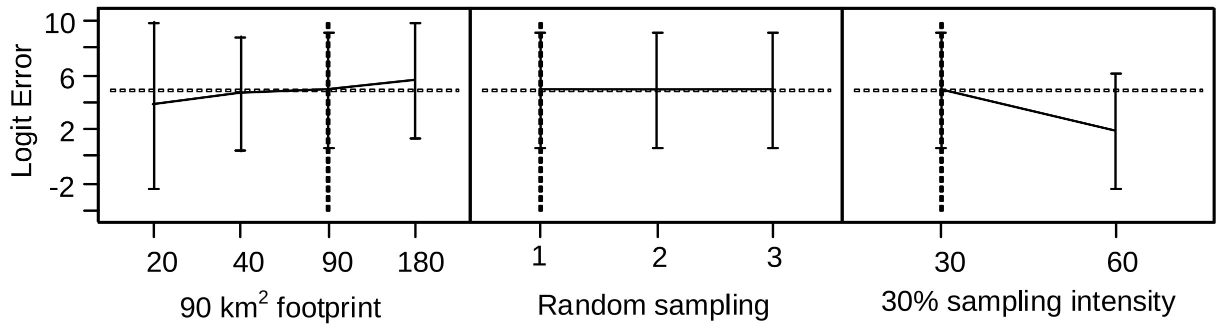
f) Varying size of the project footprint: Size = 20km^2



g) Varying size of the project footprint: Size = 40km^2



h) Varying size of the project footprint: Size = 90km^2



i) Varying size of the project footprint: Size = 180km^2