

Draft Sample Design, Field Methods, and Statistical Methods For APWRA Management Plan Research and Monitoring

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Revised Draft**

1.0 INTRODUCTION

The management goal for the APWRA is to significantly and substantially reduce fatalities of priority avian species within the APWRA. The short-term (i.e., 5-year) management objective is to reduce fatalities of target raptor species (golden eagle, red-tailed hawk, American kestrel, and burrowing owl) by 45% through management actions including, but not limited to, seasonal shut-downs, shutdown, removal and/or relocation of high risk turbines, removal of derelict turbines, and electrical modifications. Because of the uncertainty regarding the effectiveness of the proposed management actions in achieving the management objective, and the goal of generally optimizing implementation of the management measures (i.e. maximum reduction of target mortality with least loss in energy production), the initial management actions will be implemented in a stepwise fashion to achieve reductions in target raptor mortality. The initial objective of reducing mortality by 45% is based on initial estimates of the potential effectiveness of the management measures prescribed in the Condition Use Permit renewals. The conditions prescribe an implementation schedule for management measures, and specifically outline progressively increasing the implementation period for winter seasonal shutdown of turbines and increasing the shutdown of high risk turbines over the course of 3 to 5 years up to a maximum number of turbines. Subsequent steps in management may be modified based on the evaluation of the initial management actions.

Initial goals of the monitoring and research program are to evaluate the effectiveness of the seasonal shutdowns of wind turbines, and the relocation/shutdown of turbines considered high risk in reducing overall raptor mortality within the APWRA. Another goal of the monitoring and research program is to provide additional information for risk prediction within the APWRA to be used for directing future management actions, off-site mitigation, and repowering. The monitoring and research program will be conducted for a minimum of three years. The monitoring and research program will consist of fatality searches, raptor use and behavior surveys, and prey base surveys. This document describes the primary hypotheses, experimental design, and field methods.

A Scientific Advisory Committee (SRC) is being established as part of the Alameda County Conditional Permit Renewals and is an integral part of the implementation of this study plan (see Attachment D to Conditions of Permit Renewals). The SRC's purpose is to monitor the progress and effectiveness of implementation of the management actions, and to advise the County and the Wind Companies regarding future management actions that may be implemented by the Wind Companies. A primary responsibility of this group is to provide scientific expertise and peer review to implementation of this study plan.

2.0 HYPOTHESES

2.1 Seasonal Shutdown of Turbines

The research and monitoring program will evaluate the overall hypothesis related to seasonal shutdown of turbines:

H₀: Shutting down large numbers of turbines during the winter period will not reduce annual mortality of target raptor species

H₁: Shutting down large numbers of turbines during the winter period will reduce annual mortality of target raptor species.

For the general purposes of this study, seasons will be defined as:

Season	Dates
Winter	November 16 – end of February
Spring	March 1 – May 31
Summer	June 1 – September 25
Fall	September 26 – November 15

This management action consists of shutdown of large numbers of turbines within the entire APWRA during winter months, and was suggested by the companies based on review of dates of historic fatality observations, review of the CEC study report, and data, and information regarding monthly power production within the APWRA. The cause of the apparent disproportionate mortality in the winter is not well understood, but some potential risk factors have been identified. Raptor use is high in winter months and wind directions are more variable. Incidence of fog and inclement weather are also more frequent in the winter months. In addition, some operators shut down every other turbine in the winter months to improve production because wind directions are often not perpendicular to the turbine string orientations. Field methods used to gather information and statistical methods used to estimate the effectiveness of this hypothesis are described in detail in subsequent sections.

Based on estimates of seasonal mortality by Smallwood and Thelander (2004b), the proportion of mortality occurring in the winter (November 15 – end of February) ranges between 29% (golden eagle) to 47% (American kestrel).

Option	Management Measure Description	Estimated Percent Reduction in Annual Fatalities (entire APWRA)					
		GOEA	RTHA	AMKE	BUOW	4 Species Combined	All Raptors
Winter Season Shutdowns							
1	3.5 months	29%	39%	47%	35%	39%	37%
3	3 months	25%	33%	40%	30%	33%	32%
4	2 months	17%	22%	27%	20%	22%	21%

While predicted winter mortality levels suggest this management measure might be very effective in risk reduction and cost-effective in implementation, there are numerous uncertainties associated with those predictions. For example, to estimate a seasonal mortality rate, the season when each fatality occurred needs to be accurately assigned. The average search interval for the turbines monitored the longest (total time) during the previous study (Smallwood and Thelander 2004a,b) was 53 days, while the average search interval at the 2nd set of turbines monitored for a shorter time period (approximately 2500 turbines monitoring between November 2002 and May 2003) was 90 days, leading to potential uncertainties about assignment of season to each fatality, and therefore additional uncertainty in the predicted seasonal fatality estimate. Average search intervals may have varied among seasons as well, adding to uncertainty.

This study is designed to reduce many of these uncertainties, test the primary hypothesis, estimate the effect of winter shutdowns, and provide some information on optimal implementation of the winter shutdown management measure.

2.2 Shutdown/Relocation of High Risk Turbines

The research and monitoring program will evaluate the hypothesis related shutdown/relocation of high risk turbines:

H₀: Removal of turbines predicted as high risk because of their location will not substantially reduce mortality of raptors within the APWRA, where removal is accomplished by relocating turbines to sites predicted as low risk, and permanent shutdown and removal of predicted high risk turbines when no low risk location is available.

H₁: Removal of turbines predicted as high risk because of their location will reduce mortality of raptors within the APWRA, where removal is accomplished by relocating turbines to sites predicted as low risk, and permanent shutdown and removal of predicted high risk turbines when no low risk location is available

Given the relatively small number of turbines initially selected for shutdown, removal, or relocation, the uncertainty in baseline fatality rates, and the differences in search intervals between the pre- and post-management period (50 to 90 days during the CEC study, approximately 30 days proposed for this study), the ability to statistically determine a

reduction in mortality from this measure alone will be low. Therefore, the approach to evaluate this management measure will focus on validation of previous turbine risk models, and development of new and updated risk models. These models will then be used to modify temporary selections of turbines to shut down, or advise future selections of turbines for shutdown. This information will also be useful for predicting potential high or low risk locations for repowering (See section 6.0).

3.0 Sample Design

The sampling design for testing the seasonal shutdown hypothesis and for estimating the effect of seasonal shutdowns will be a cross-over design¹. The analysis for evaluating the effect of shutting high risk turbines down can generally be characterized as a Before/After/Control/Impact Design (BACI, Anderson et al. 1999, Morrison et al. 2001). Fatality, avian use and behavior metrics, and statistical models of collision risk prediction will be the primary measures used to evaluate the effectiveness of the management measures.

3.1 Sampling Universe

All turbines of participating companies within the APWRA were considered, with the exception of the Buena Vista turbines that are planned for repowering. This resulted in approximately 4,800 turbines available for study (i.e., sample universe). The sample universe includes some turbines that were not sampled during the previous research by CEC (Smallwood and Thelander 2004a,b), and excludes the Buena Vista turbines, and turbines from non-participating companies.

3.2 Primary Stratification of the APWRA

Two primary levels of stratification (geographic location and turbine size) were considered in designing the experiments for this monitoring and research study. The first stratification (geographical location) was used for the implementation of the seasonal shutdown management action and to provide some level of interspersions of the sample sites across the entire APWRA. The North/West and the North/East portion of the APWRA, hereinafter referred to as the North stratum, includes turbines from participating companies located in the north and western portion of the area defined by: north of I-580 and north of Altamont Pass Road in both Alameda and Contra Costa County (Figure 1). The South/West and the South/East portion of the APWRA hereinafter referred to as the South stratum consist of the western and eastern portions of the remaining turbines (Figure 1).

¹ A cross-over design is a research design where **the subjects get both treatments in sequence**. In this example, the two treatments are turbines shut down and turbines operating. In the first winter, half the turbines are shut down while the other half are operating. In the 2nd year, the treatments are switched. The cross-over design represents a special situation where there is not a separate comparison group. In effect, **each subject serves as his/her own control**. Also, since the same subject receives both treatments, there is no possibility of covariate imbalance (<http://www.cmh.edu/stats/definitions/crossover.htm>).

Turbine size was also considered to help balance sample sizes among different turbine sizes, and as an indirect result, provided some balanced representation among turbine types and turbine owners. Turbines were grouped into three levels of turbine size based on nameplate turbine size category. The three categories were:

Very Small:	40-65 kW
Small:	100-150 kW
Medium:	≥ 250 kW

3.3 Sampling Blocks

All turbine strings were grouped into sampling blocks using a Geographic Information System (GIS). The number of turbines per block varied from approximately 10 to 60 turbines and 1 to 7 strings. Turbine strings were grouped into blocks based on turbine size and type and proximity of strings to each other (Figure 1). Samples of these turbine blocks were selected based on the sampling scheme below. All turbines within a selected block will be searched for fatalities during a given search day. This sampling approach (blocks of strings instead of individual strings) is more efficient and increases the time spent searching and subsequently decreases the time necessary to travel between search areas.

3.4 Sample Selection

A random sample (or census in some cases) of turbine blocks was selected within each of the combinations of strata yielding approximately 2000 turbines in the sample for the first year (Table 1). Modifications to the sample size may be made in the 2nd year, depending on the results of the first year's monitoring, subject to review by the SRC. Fatality searches will be conducted at all turbines within the selected turbine blocks.

3.4.1 40-65 kW Turbines (Very Small Turbines)

All small turbines within the sample universe will be sampled during the first year (Table 1), which includes approximately 313 turbines in the North/East portion of the North stratum (40 and 65 kW), and 449 in the South/East portion of the South stratum (65 kW). The larger sample in the South/East area is being conducted at least for the first year because most of those turbines have been searched on a systematic basis since January 2005, and this will allow for continuity and additional information. Another reason for selecting all turbines of this size to sample is that the strings themselves are close enough together that 50-m plots of a particular string would include adjacent strings. If we only took a sample of plots within this category, thus it would be difficult to standardize the fatality information by the number of turbines sampled.

3.4.2 100-150 kW Turbines (Small Turbines)

This category has the largest number of turbines, and includes primarily KCS 56-100 turbines on lattice towers, but also includes Danwin 110 kW turbines, Vestas V-17 and V-19 turbines, and Bonus 120 kW and 150 kW turbines. To ensure interspersions of samples among turbine types and geographical areas within the APWRA, the following approach was used to sample from this stratum.

Approximately 550 turbines will be sampled in the North/East and North/West portions of the North stratum, and 550 turbines will be sampled in the South/East and the South/West portion of the South stratum during the winter period based on the random sample of turbine blocks identified in Figure 1. This will be decreased by approximately 1/3 during the remaining seasons when the study focuses on the effectiveness of removal/relocation of high risk turbines (last 1/3 of turbines randomly selected).

Table 1. Approximate number of turbines and turbines identified to be sampled within the North/West and North/East (combined into North stratum) and South/West and South/East (combined into the South stratum) within three turbine size classes. This selection process is subject to review and may change. Final Table with field verified information will be available in mid December.

Size Class	Approximate No. Turbines Considered ^a		Approximate No. Turbines Sampled ^b	
	North	South	North	South
Smallest (40 – 65 kW)	313	426	313	426
Small (100 – 150 kW)	2300	1654	561	601
Medium (250 – 400 kW)	106	37	106	37
Subtotal	2721	2140	980	1064

^a does not include turbines from non-participating companies or turbines at the Buena Vista site, which are planned to be repowered.

^b may include some currently non-operational “derelict” turbines

3.4.3 > 250 kW Turbines (Medium Turbines)

This stratum includes the WEG 250 kW turbines, KVS-33 400 kW turbines, and the Howden 330 kW turbines. All turbines of this size will be sampled year-round (Figure 1, Table 1) given the small number of turbines in this category. The Howden 330 kW turbines have been searched on a monthly basis since spring 2005.

4.0 Field Methods

4.1 Fatality Searches

To ensure comparable data, fatality searches will be conducted using a protocol similar to the one used by Smallwood and Thelander (2004a,b). Searches will be conducted within rectangular search plots with boundaries a minimum distance of 50 m from the turbines within each selected sample block. Plots at the newer and larger turbines (≥ 660 kW) will be extended to 75 m to account for their larger size. To allow an estimate of total fatalities, carcass removal and carcass detection bias will be estimated following the methods described in Erickson et. al. (2004) and Kerns et al. (2005). Searches will be conducted at each of the selected turbines on an approximately monthly basis. During set up (late September – mid-October and during the first search (October – early November) all fatalities will be documented and removed for the start of the winter season and the seasonal shutdown experiment.

4.2 Avian Use and Behavior

Studies have previously quantified avian use and behavior within the APWRA (Orloff and Flannery 1992, Smallwood and Thelander 2004a,b, Hoover and Morrison 2005). During this study, approximately 1 avian use and behavior station will be located and surveyed for every turbine block (every other block for Very Small turbines since blocks in this category are close together), resulting in approximately 50 avian use survey stations for documenting avian use and behavior from 360° visual scan surveys. This number of stations results in approximately 1 station located every 1 square mile within the APWRA. An additional 10 stations will be located in association with areas where no turbines exist (reference sites). The final locations will be determined in the field, and will be established to ensure good viewsheds and proper identification of bird species near turbine strings, but far enough away from turbines to minimize observer bias.

Each 360° visual scan will last 30-minutes. During the first 10 minutes, a count of all birds seen will be recorded. During the remaining count, only raptors and other large birds will be counted (e.g., waterfowl, other waterbirds, ravens). A minimum of one visit to each survey point will be conducted each month during the monitoring period. Bird use and activity sampling effort will be stratified by time of day; behaviors will be divided between those observed during morning and afternoon sessions. The morning sessions start at 0700 hrs and continue until 1200 hrs. The afternoon sessions last from 1201 hrs until 1800 hours. Environmental conditions will be recorded at the beginning of each session and include temperature, wind speed, and cloud cover.

Data recorded for each observation will follow similar methods used by Smallwood and Thelander (2004a,b), which were initially developed by Hoover (2001) and published in Hoover and Morrison (2005). When raptors and large birds are detected, the corresponding information will be entered onto data sheets and maps using an alphanumeric coding system. The location of each bird or flock is marked sequentially on the map every minute. With a topographic map available for each observer on each plot and each session, the observer can plot sequential numbers onto the map corresponding with the locations of raptors observed at regular intervals (1-minute). Attributes will be associated with each plotted number including species, number of individuals seen, whether it is the same individual or group as previously recorded, specific behavior (e.g., soaring, contour hunting, “fly-through”), height above ground, and type of perch being used. If perching is observed, the time and specific perching structure will be recorded. Perching structures are grouped into four different categories: (1) turbine devices, (2) electrical distribution poles, (3) metal/electrical towers, and (4) landscape features (e.g., rock piles, fences, etc.). After the observation session, these attributes will be entered into a computer spreadsheet. All plotted numbers which are linked to the attribute data will then be digitized and managed as a GIS database, and analyzed to test hypotheses specific to this and other wind power projects.

4.3 Carcass Removal Studies

Carcass removal studies will be conducted throughout the monitoring year. Estimates of carcass removal will be used to adjust carcass counts for removal bias in overall fatality estimates. Carcass removal includes removal by predation or scavenging, or removal by other means.

During the first year of monitoring, approximately 20 bird carcasses will be distributed during the start of each of six trials, resulting in a total of approximately 120 trial carcasses used in carcass removal studies for the first year of monitoring. The start dates of each trial may be spread over a few days. However, the start dates of each trial should be at least 3 weeks apart. The resulting data will be evaluated to determine the need for this component of study in the subsequent monitoring years. Species such as rock doves, hen mallards, fresh raptors (those approved of by USFWS), and hen pheasants will be used. These carcasses will be randomly placed within 50 m of turbine strings that are not part of the sample for fatality searches. Fresh turbine fatalities will be left as found if they are to be included in the carcass removal trials.

Carcasses will be checked as follows, although actual intervals may vary. Carcasses will be checked for a period of 60 days to determine removal rates. They will be checked approximately every day for the first 3 days, and then approximately every 4 to 6 days depending on schedules of other surveys. Experimental carcasses will be marked discreetly using a piece of tape on one leg for recognition by searchers and other personnel. Experimental carcasses will be left at the location until the end of the carcass removal trial. Any remaining trial carcasses will be removed at the end of the 60-day period. Comparisons of carcass removal rates will be made between raptors and other groups used (e.g., rock doves). In addition to the bird carcasses, separate trials using fresh bats will be conducted, if fresh bat carcasses are available.

4.4 Searcher Efficiency Studies

Searcher efficiency studies will be conducted in the same areas as carcass searches, with the exception personnel conducting the searches will not know when trials are conducted or the location of the detection carcasses. Estimates of searcher efficiency will be used to adjust the number of carcasses found, correcting for detection bias. At a minimum, this information will be used in making new annual mortality estimates.

During the first year of monitoring, approximately 20 bird carcasses will be distributed during the start of each of six trials, resulting in a total of approximately 120 carcasses used in searcher efficiency studies. Species such as rock doves, hen mallards, hen pheasants, and raptors will be used.

All carcasses will be placed at random locations within areas being searched prior to the carcass search on the same day. If avian scavengers appear attracted to the placement of the carcasses, the carcasses will be distributed before dawn. Carcasses will be dropped from waist height.

Each trial carcass will be discreetly marked so that it can be identified as a study carcass after it is found. The number and location of the detection carcasses found during the carcass search will be recorded. The number of carcasses available for detection during each trial will be determined immediately after the trial by the person responsible for distributing the carcasses. In addition to the bird carcasses, separate trials using fresh bats will be conducted, if fresh bat carcasses are available.

4.5 Ground Squirrel and Pocket Gopher Activity Surveys

Ground squirrel and pocket gopher burrow system centroids (Smallwood and Thelander 2004b) will be mapped along 300-ft long transects distributed throughout the APWRA. Approximately every fourth turbine selected for fatality searches will be sampled to provide an index of ground squirrel and pocket gopher activity for each turbine string. A transect (“turbine transect”) will be established at each selected turbines and will be orientated perpendicular to the turbine string orientation. In addition, “reference transects” will be established at every reference avian use station (10 stations). The resulting spatial distribution of this index of activity for ground squirrels and pocket gophers will be used in the analysis of observed spatial pattern of raptor fatalities as well as to the GIS database of raptor flight and perch locations. Comparisons of the activity index will also be made between the reference transects and turbine transects. Surveys for target prey activity will be conducted once per monitoring year on each sampled transect.

5.0 Statistical Analysis

Statistical analysis methods will evaluate the effect of the two primary management measures being implemented (1) winter season shutdown of turbines, and (2) shutdown, removal or relocation of high risk turbines. In addition, estimation of total annual raptor and other bird fatality rates will follow Erickson et al. (2004) and Kerns et al. (2005). Other statistical methods or techniques may be used, if approved by the SRC.

5.1 Seasonal Shutdown Experiment

The study will only rely on new fatality information to make statistical inferences regarding the effect of seasonal shutdown.

The cross-over design should provide a powerful analysis of the overall effectiveness of seasonal shutdown. The analysis will use the following notation.

Define \bar{x}_{ijk} , as the mean observed per turbine (or per MW) fatality rate within the *i*th stratum (*i*=N (North) or S (South)), *j*th monitoring year (*j*=1 or 2), and *k*th period (*k*=A for Mar. – Oct., B for Nov. – Dec., and C for Jan. – Feb.).

Time Period	Year 1 ¹		Year 2 ²	
	North	South	North	South
March – October	\bar{x}_{N1A}	\bar{x}_{S1A}	\bar{x}_{N2A}	\bar{x}_{S2A}
Nov – Dec.	\bar{x}_{N1B}	\bar{x}_{S1B}	\bar{x}_{N2B}	\bar{x}_{S2B}
Jan. – Feb.	\bar{x}_{N1C}	\bar{x}_{S1C}	\bar{x}_{N2C}	\bar{x}_{S2C}

¹ turbines in the North block will be shut down from November 1 – December 31

² turbines in the North block will be shut down from January 1 – February 28

The hypotheses described in the section X for seasonal shutdown are equivalent to the following quantitative hypotheses:

$$H_0: \mu_w = 0$$

$$H_1: \mu_w > 0$$

where μ_w is the winter period operating turbine fatality rate. This statistic will be estimated by:

$$\hat{\mu}_w = \hat{\mu}_{wo} - \hat{\mu}_{wn}$$

$$\hat{\mu}_{wo} = (\bar{x}_{N1C} + \bar{x}_{S1B} + \bar{x}_{N2B} + \bar{x}_{S2C}) / 2$$

$$\hat{\mu}_{wn} = (\bar{x}_{N1B} + \bar{x}_{S1C} + \bar{x}_{N2C} + \bar{x}_{S2B}) / 2$$

The overall effect of winter shutdown will be estimated as the proportion of the total wind project mortality that occurs with operating wind turbines in the winter period:

$$\hat{E}_w = \frac{\hat{\mu}_w}{\hat{\mu}_A}$$

$$\text{where } \hat{\mu}_A = ((\bar{x}_{N1A} + \bar{x}_{S1A} + \bar{x}_{N2A} + \bar{x}_{S2A}) / 4) + ((\bar{x}_{N1C} + \bar{x}_{S1B} + \bar{x}_{N2B} + \bar{x}_{S2C}) / 2)$$

This estimate assumes that all fatalities recorded are attributed to the wind project. If some of the mortality is unrelated to the wind project, then \hat{E}_w will underestimate the effectiveness of the winter shutdown. Bootstrapping (Manly 1997) will be used to provide estimates of standard errors and 90% confidence intervals.

Simulations were conducted in SAS (SAS Institute 2000) to estimate the statistical power to reject the hypothesis of no effect from the winter shutdown. Statistical power was ($\alpha=0.05$ one-tailed) was calculated assuming $\hat{\mu}_A$ follows a Poisson distribution with values of 0.01, 0.05, and 0.10, $\hat{E}_w = 0.25, 0.35$ and 0.45 for sample sizes of 2000 total turbines and two years of data collection. In addition, the half width of bootstrap derived 90% confidence intervals for \hat{E}_w was estimated (estimated as a function of % of \hat{E}_w). Figure 2 shows estimated statistical power for testing the effectiveness of seasonal shutdown. If annual observed target raptor mortality is 0.05 to 0.10/turbine/year for operating turbines in the Altamont, statistical power will be greater than 90% to pick up an effect of 25% to 45% of winter shutdown, if the proposed sample size is achieved. Figure 3 shows the estimated half-widths of the confidence intervals around \hat{E}_w . Power will be moderate for individual species such as burrowing owl, golden eagle, and American kestrel (0.01 to 0.02 per turbine per year observed) and high for all raptors combined, target raptors combined, and red-tailed hawks. These calculations assumed 2 years of collection. A third year should greatly increase the power for the first three species. Adjustments to these analysis methods will be made if searcher efficiency or carcass removal estimates during the winter season are significantly different than the estimates from the other seasons combined.

5.2 High Risk Turbine Shutdown/Relocation

Two approaches will be used to evaluate the effectiveness of turbine shutdown. As described previously, numerous approaches for modeling and mapping high risk turbines combined across the target raptor species have been previously implemented and several maps of potentially high risk turbines have been developed (Smallwood 2004, Smallwood and Spiegel 2005a,b,c). The number of turbines selected to shut down or relocate in the first few years of the implementation of this measure, and the high uncertainty in the baseline fatality rates estimated during the previous study, will limit the statistical power to detect the fatality reduction by this management measure alone. Therefore, initial evaluation of this approach is to use the first two years of fatality data to independently validate the previous risk models and turbine risk maps, and develop new or updated collision risk models. An observed average fatality rate for focal raptor species will be calculated for each risk category (Tier 1 - Tier 5) of previous risk maps. Risk maps will be compared by calculating the observed raptor fatality rate for a fixed number of MW associated with the highest risk turbines or a fixed number of highest risk turbines for the different maps. The risk maps that show the highest mortality rates for a fixed number of turbines or MW to shut down will be considered the best predictors of risk. A hypothetical example in Figure 4 illustrates the approach. In this strictly hypothetical approach, risk map 3 would be considered the best predicted risk map. Other validation techniques may be conducted, if approved by the SRC.

In addition, new or updated statistical risk models will be developed after the first two years of new fatality information. Logistic regression modeling was considered

previously by Smallwood and Thelander (2004b); however' due to the author's concern over incorporating differential sampling efforts among turbines (search intervals, seasons) into the regression modeling, they focused on the combination of results from univariate analyses. Logistic regression or another appropriate multivariate modeling technique will be considered for predicting the probability of fatalities occurring as a function of the characteristics of the turbines. The form of the logistic regression equation is:

$$p = \frac{e^{\beta_0 + \beta_1 x_1 + \dots + \beta_n x_n}}{1 + e^{\beta_0 + \beta_1 x_1 + \dots + \beta_n x_n}}, \text{ where } x_i, i=1 \text{ to } n \text{ are the variables related to collision risk, and } \beta_i \text{ are the model coefficients.}$$

Akaike's Information Criterion (AIC) (Burnham and Anderson 2002) will be used to rank the models according to how well each model describes the data. The AIC value for each model will be calculated as

$$AIC = -2 \ln(\text{Likelihood}) + 2k ,$$

where k is the number of parameters in the model (including intercept term), *Likelihood* is the value of the logistic likelihood evaluated at the maximum likelihood estimates, and 'ln' is the natural logarithm.

Model averaging based on the AIC weights (Burnham and Anderson 2002) for each model fit will be used for final predictions of the probability of fatalities, \hat{p} . AIC weights will be calculated for each of the m models using

$$w_i = \frac{\exp(-\frac{1}{2} \Delta_i)}{\sum_{r=1}^m \exp(-\frac{1}{2} \Delta_r)},$$

where Δ_i is the AIC difference calculated using

$$\Delta_i = AIC_i - AIC_{\min} .$$

An AIC weight is considered as the weight of evidence in favor of model i being the "best" model for the data given that the actual "best" model is one of the models fit (Burnham and Anderson 2002). The weighted model average estimate of the probability of fatality will then be calculated as

$$\hat{p} = \sum_{i=1}^m w_i \hat{p}_i .$$

Models will be developed separately for each target species, if data are sufficient. For the new models, we recommend a set of *a priori* selected candidate variables be determined before modeling occurs, to alleviate concerns over potential spurious model results when a large number of inter-correlated variables are considered. It is recommended the SRC aid in developing the list of candidate variables to consider. These new models may be independently validated by previous fatality information (Smallwood and Thelander 2004a,b) using a similar approach to the one above for the existing maps and models. Other modeling approaches may also be used based on recommendations from the SRC.

6.0 References

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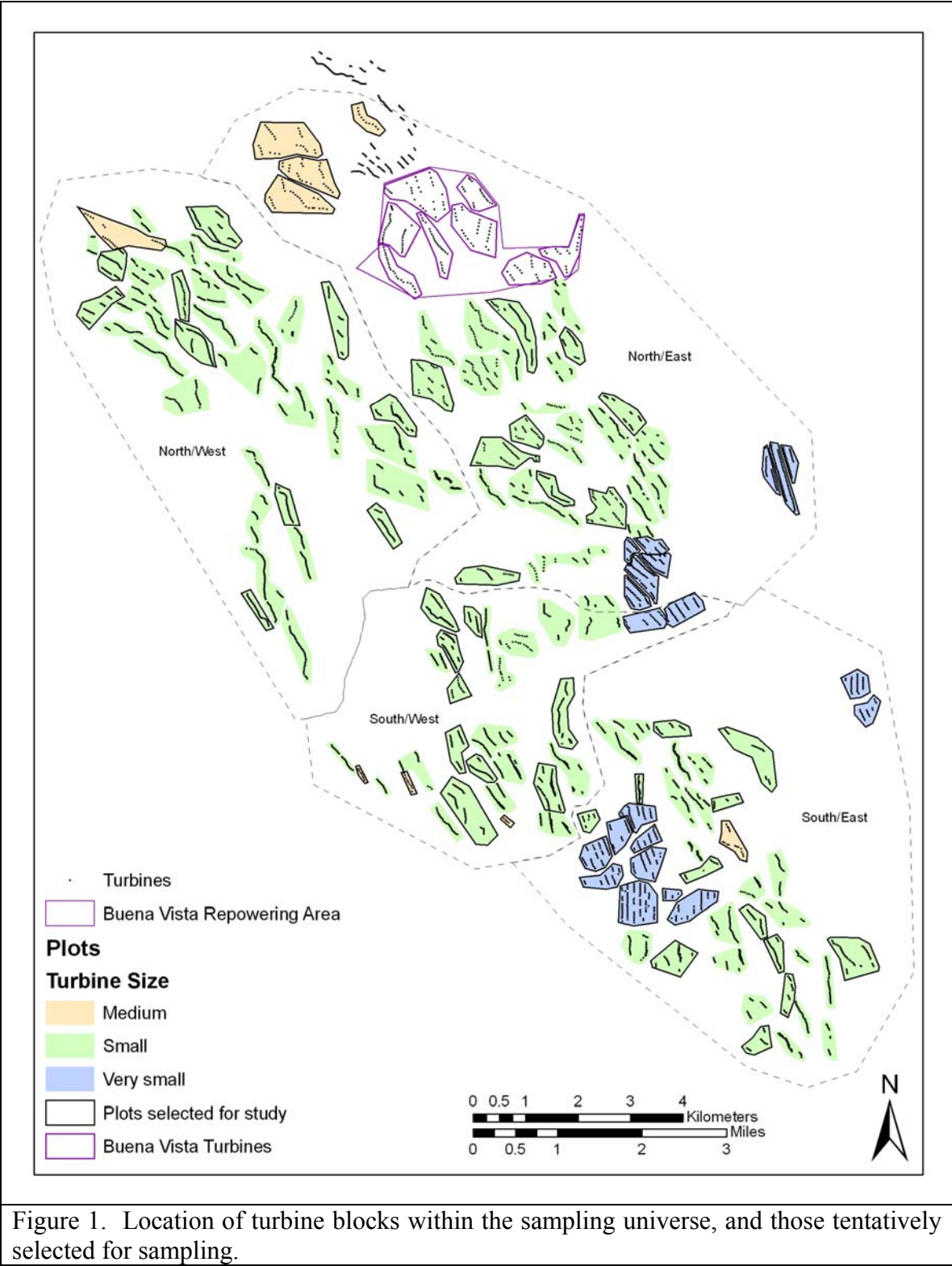


Figure 1. Location of turbine blocks within the sampling universe, and those tentatively selected for sampling.

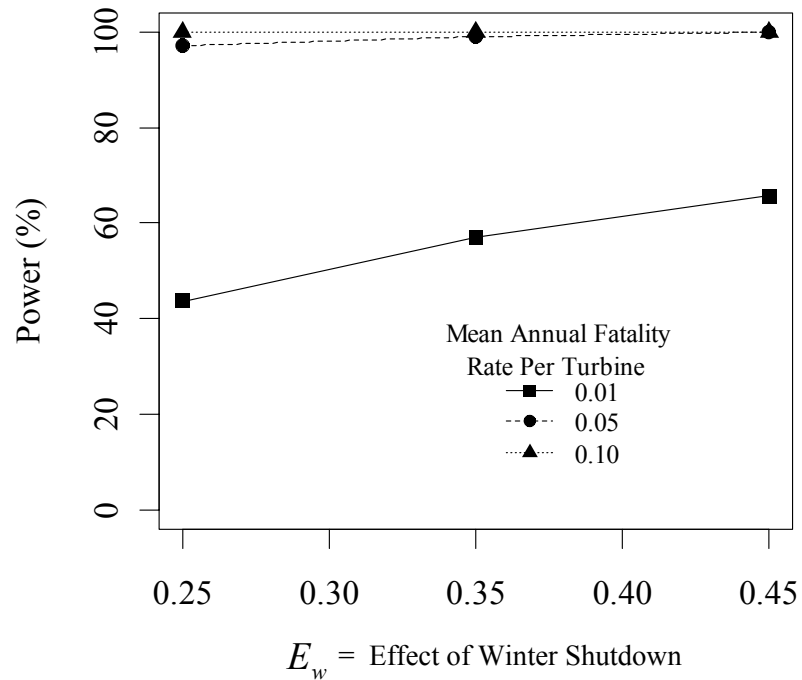


Figure 2. Statistical power for testing the effectiveness of seasonal shutdown for different values of μ_A (0.01 fatalities per turbine, 0.05 fatalities per turbine, and 0.10 fatalities per turbine) and different values of E_w (0.25, 0.35, and 0.45), assuming background mortality is 10%.

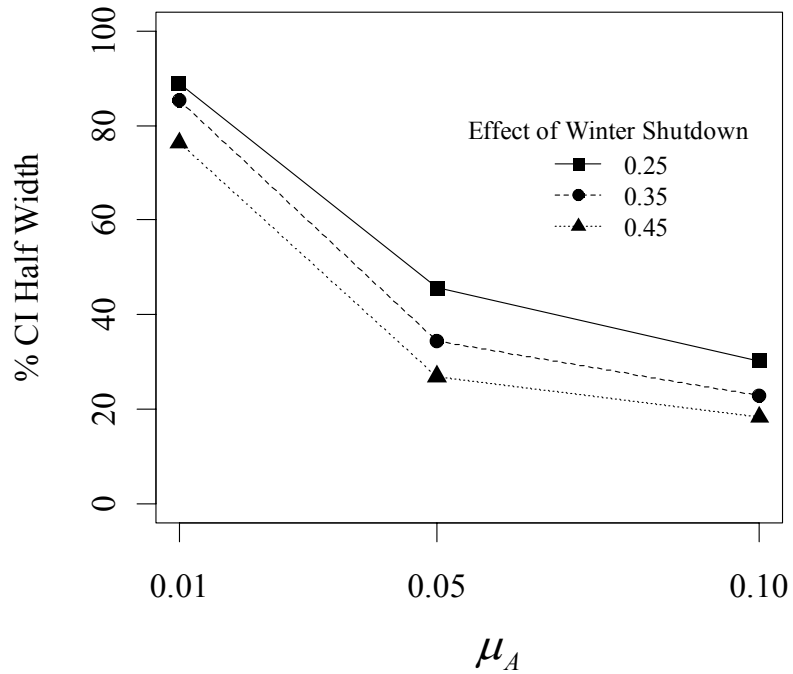


Figure 3. Estimates of the confidence interval half-width expressed as a percent of the estimate of E_w , assuming a sample size of 2000 turbines, and values of μ_A of 0.01, 0.05, and 0.10 fatalities per turbine.

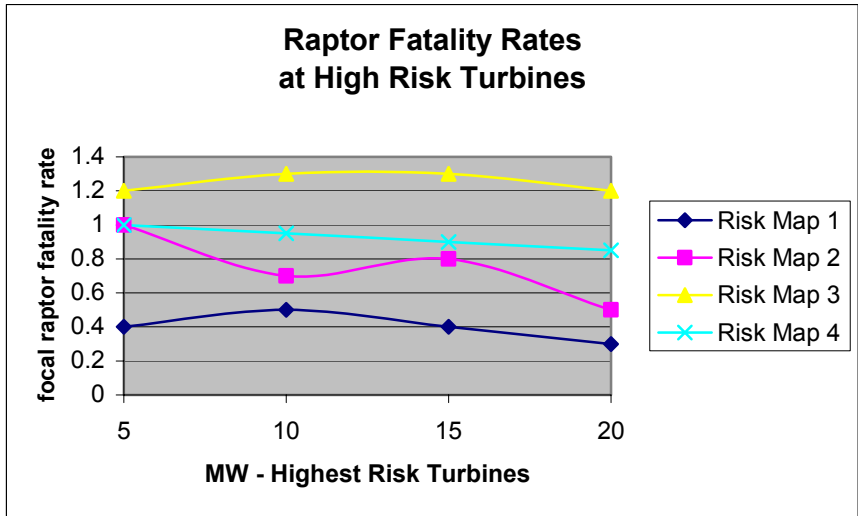


Figure 4. Hypothetical example illustrating one technique for independently validating previous risk models with new fatality information. The y-axis is the new observed fatality rates estimated for the turbines considered highest risk for each of 4 risk maps.