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Date:	7-7-08
To:	AWPRA Scientific Review Committee
cc:	Brian Kara Ed West Kort Clayton
From:	Jesse Schwartz
Subject:	**Estimation of carcass detection efficiency at the Altamont Pass Wind Resource Area: A proposed Study**

Introduction

Estimates of turbine related bird mortality at the Altamont Pass Wind Resource Area (APWRA) depend upon on the ground field surveys of bird fatalities.. The precise number of fatalities at APWRA cannot be determined because not all turbines are surveyed, surveyors do not detect all fatalities (searcher efficiency error) and scavengers often remove carcasses before they can be detected (scavenging error). Therefore, to provide a statistically valid measure of bird mortality, estimates of searcher efficiency error and scavenger error must be made and used to adjust the observed mortality within the APWRA survey area.

There are additional sources of error (Smallwood 2007) which the proposed monitoring approach will not address directly. One source of error is crippling bias; the rate at which birds are mortally wounded by wind turbines but then leave the search area on their own volition before the searchers have a chance to detect them. Another is search radius bias, which refers to the number of bird carcasses deposited by the wind turbines outside the currently used search radius of 50 m from turbines. Another is background mortality, which can inflate mortality estimates attributed to wind turbines. One issue is the duration of the monitoring program – the longer the program, the more species will likely be included in mortality estimation. Finally, a source of error could be the choice of denominator in the mortality metric. Currently, relating the number of dead birds to MW of rated capacity of the wind turbines is the standard, but the number of dead birds has also been related to the number of wind turbines searched, and could be related to the power output of time of operation of the wind turbines since the last fatality search. We do not know the magnitudes of the sources of error just listed, but we recognize they remain insufficiently characterized for use as adjustments of mortality estimates.

The aim of our proposal is to eliminate sources of bias and error related to scavenger removal and searcher detection trials, as well as error stemming from the interaction of scavenger removal and searcher detection rates. Traditionally, bird mortality at wind power facilities has been estimated by adjusting the number of observed fatalities using empirical measures of scavenging rates, and actual surveyor detection efficiency (Smallwood and Thelander 2004, Smallwood, 2007). However, because these error factors interact synergistically (occur together over the survey interval) it is logistically and mathematically difficult to separate and identify accurate error values for each. Previous studies have calculated separate values for searcher efficiency and scavenger rates (e.g. Smallwood, 2007) which were then used additively to calculate adjusted mortalities. This method, which has been used previously to adjust fatality estimates in the APWRA, has been brought into question because it can potentially result in over- or under-estimations of the actual number of fatalities, depending on the relative magnitude of the calculated values. This bias would be particularly prevalent in estimates of adjusted mortality for birds that are readily scavenged and for small birds that are easy to miss during the field surveys. For example, smaller birds such as burrowing owls are subject to relatively high scavenger rates, and are more cryptic in the field than larger birds such as red tailed hawks.

Improvements in the estimation of the overall detection efficiency should, in theory, improve the estimate of overall fatalities. This memo outlines a general approach and statistical power analysis for estimating detection efficiency in the field. The approach does not differentiate between “searcher efficiency” (“P” from Smallwood, 2007) and “scavenger efficiency” (“X” from Smallwood, 2007) per se, but the power analysis is based on the previous estimates of these variables. The results of the proposed study could be used to replace the “estimates” of X and P with a combined detection probability “X*P” known as “θ” in the CJS literature. The simple detection or “carcass” detection probability is calculated as:

Equation 1

$$(X * P) = \theta = \frac{sizeofmarkedpopulationat : time(t+1)}{sizeofmarkedpopulationat : time(t)}$$

The equations for calculating confidence intervals for these estimates are described in detail in Krebs (1989). The adjusted estimates of fatalities are then calculated using the same approach outlined by Smallwood (2007) where:

Equation 2

$$adjustedFatalities = \frac{numberoffatalities}{\theta}$$

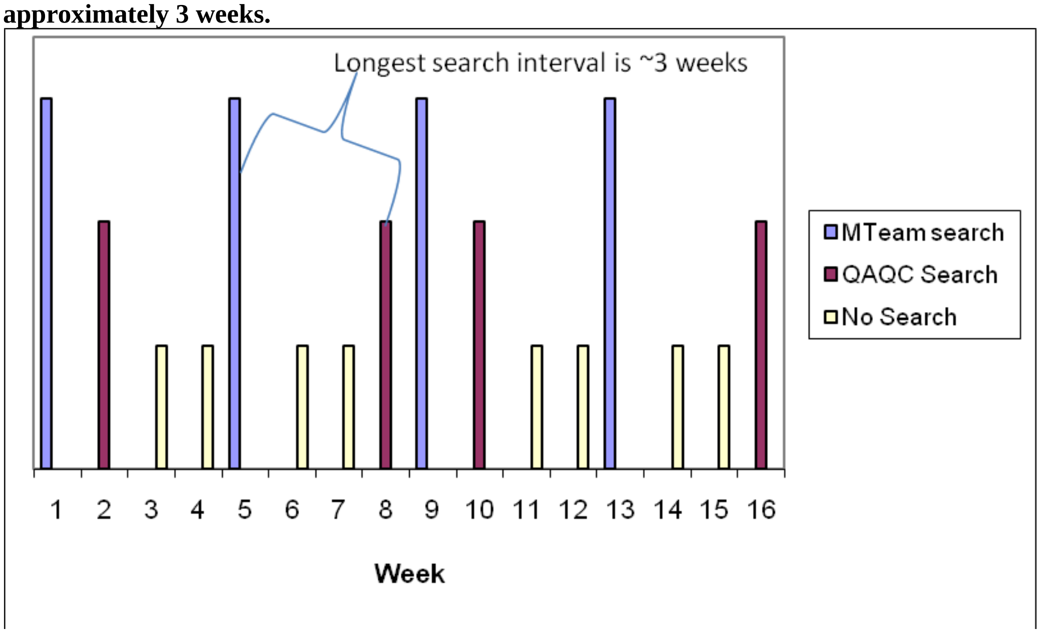
However X*P (scavenger rate times searcher efficiency) is replaced with θ which is the overall probability of detection based on all sources of error.

Approach and Methods

Fatalities occur without direct observation at APWRA. Bird carcasses or portions of carcasses (“carcasses”) remain in the field until they are detected or not detected due to scavenging, searcher intensity (i.e. search intervals), and searcher efficiency. During the period between the actual fatality and the detection or missed detection the carcasses are exposed to scavenging and decay. Biologically this scenario is equivalent of a “survival” study. The term “survival” study in this instance could be a bit confusing, because it refers to whether or not a carcass “persists” in the field – and is not analytically related to the actual “fatality”. The methods described here are focused only on the discovery of carcasses and not the fatality events themselves.

Cormack (1964), Jolly (1965), and Seber (1965) (CJS) developed mathematical and statistical methods for estimating survival in the field based on a “mark-recapture” design. The CJS design involves “marking” a number of animals in the field, and then subsequently searching for them again. The fraction of “recaptures” can be used to estimate the overall “survival” of carcasses in the field. In providing an empirical measure of carcass survival this determination also provides an empirical-based estimate of overall carcass detection probability (X*P) under all possible searcher efficiency/scavenger rate permutations. The CJS technique has been extensively reviewed and refined to address a number of survival issues, and a considerable amount of resources have been invested in computer software for managing and analyzing this data. I propose the implementation of a CJS mark-recapture design as a pilot study for the APWRA monitoring program to provide a more reliable and accurate adjustment factor for estimating species-specific bird mortality. Beginning November 1, 2008 the monitoring team would begin to mark carcasses of specific species (see below) in the field using a unique identifier, and leaving those birds on the ground after collecting photographic, demographic, and biological samples. To implement the CJS study, a two-person team (QA/QC Team) would survey turbines 1 to 3 three weeks before and 1 to 3 weeks after the regular monitoring team makes its visit. All carcasses detected by the QA/QC Team would be “marked” and left in place as well, those later found by the regular Monitoring Team would be considered “recaptured” because they were re-discovered. In this way all carcass of the “proxy species” (see below) will be marked at a particular subset of the turbines in the APWRA, and will provide an opportunity for “recapture” or re-observation within ~3 weeks following the stratified two team design.

Figure 1. Theoretical search timeline for the regular monitoring team (MTeam) and QAQC Team (QAQC Serach). The bracket shows that that longest interval between searches at a QA/QCd turbine would be approximately 3 weeks.



To improve the focus and cost-effectiveness of the effort, the QA/QC Team would survey a subset of the overall turbines currently in the APWRA monitoring design. The QA/QC Team would follow field techniques identical to those used by the regular monitoring team. The QA/QC Team would search for, and detect, fatalities on the ground at APWRA. Fatalities associated with turbines (within the 125 ft radius of the turbine, and at turbines associated with the current study design) would be "marked" in the field. The GPS location and all fatality-specific information collected during regular monitoring events would be recorded. These protocols for conducting fatality monitoring have been previously described and reviewed in considerable detail, and will not be repeated here. In addition individual carcasses will be marked with a non-discernable (cryptic to scavengers) feature such as a field tag or marking chemical. The precise nature of the mark should be discussed and considered carefully prior to the implementation of the QA/QC study to avoid its increasing the detectability of the carcass.

The QA/QC Team survey schedule would be structured such that QA/QC surveys occurred 1-3 weeks prior to the survey by the monitoring team, and subsequently 1-3 weeks following the monitoring team survey on all subsequent passes. For this initial pilot study I recommend a study period of one year, though the surveys could be truncated to a portion of the year as discussed below. This stratification would help ensure that carcasses of different ages (fresh versus ~30 days old) are "marked" in the field. The monitoring team would conduct regular surveys on turbines that overlap with the QA/QC team, but would make note of "recaptured" carcasses based on the field mark that was used by the QA/QC team.

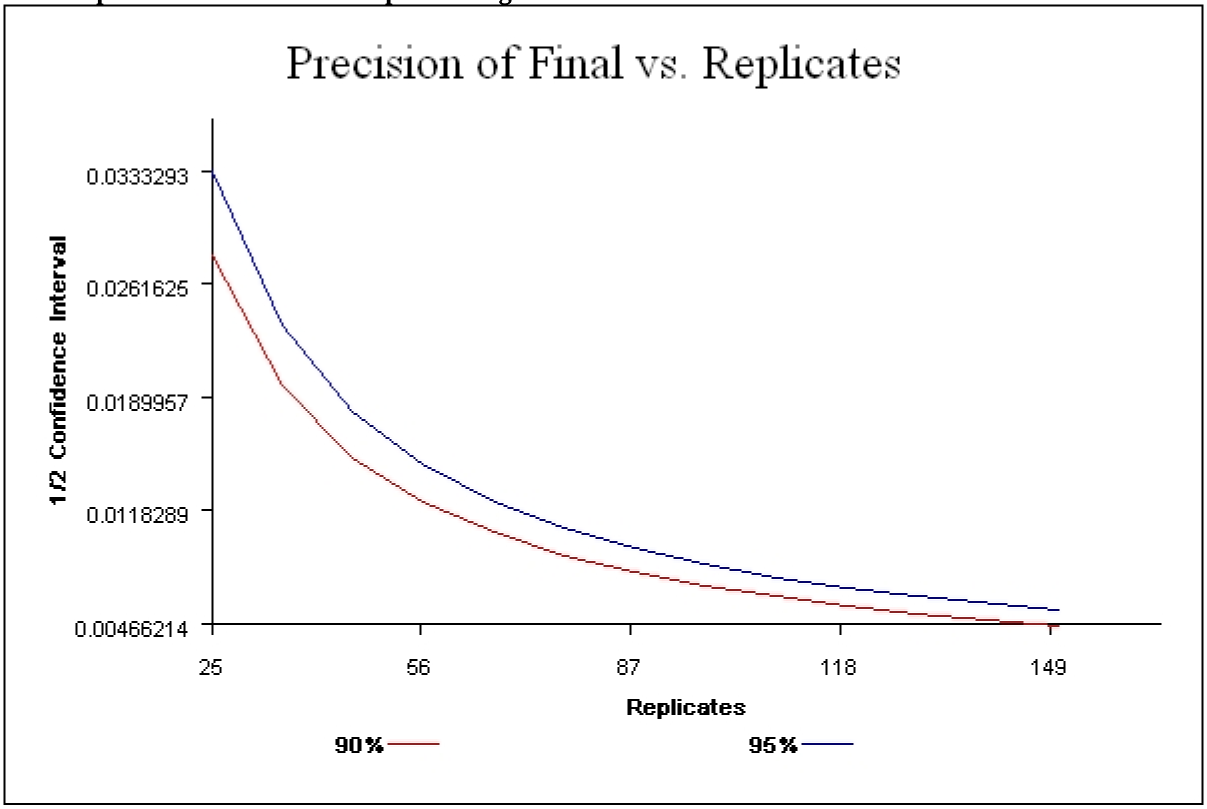
In a CJS mark-recapture design, the resulting information (number marked versus number unmarked carcasses found) is then used to estimate the "survival" of the carcass as a cumulative probability equal to the actual survival (i.e. scavenger efficiency) times the probability of detection (i.e. searcher efficiency)(see equations 1 & 2 above). This metric can be calculated for any species, taxa group or size class of interest, which can then be used to more accurately expand the estimated total number of carcasses found within the survey area to the total number of fatalities in the APWRA system.

The statistical power (the probability that the test will reject a false null hypothesis or that it will not make a Type II error) of the CJS design is influenced by the number of marks and the potential to recapture or "re-observe" marked animals in the field. The potential for recapturing animals is a function of the probability of carcasses being scavenged, and error associated with searcher efficiency. Based on previous observations, the average age of carcasses found on APWRA during the current study period of 2005-2007 was 31 days, with some variance across species. The QA/QC pilot study would be designed to result in a search interval at any QA/QC'd turbine of no longer than 30-40 days. Some carcasses may be subsequently missed by the monitoring team, and "recaptured" (re-observed) by the QA/QC on additional passes, and would be older than 30 days. However, the number of birds biasing the power analysis in this matter should be small and not influential on the statistical design. Therefore, we used an average scavenger risk for ~30 day old birds when estimating the sample size needed to conduct this experience.

Previous estimates of the probability of a 30 day old carcasse remaining in the field (i.e. not being scavenged) were ~32% for small raptors, and ~93% for large raptors (Smallwood 2007). The probability of a searcher detecting a given carcass is ~74% for small raptors, and ~80% for large raptors (100% for very large raptors, but 80% is the conservative estimate for the species discussed below). Therefore, the probability of a fatality being detected within a 30 day search interval is the product of the carcass survival probability and the searcher detection probability for each raptor size group: 32*74=23.68% for small raptors, and 93*80=74.34% for large raptors.

I used these preliminary estimates of overall detection efficiency to estimate the number of birds that must be marked in order provide a statistically reliable estimate of detection efficiency on an annual basis. I used Sample Size version 1.3 (www.cbr.washington.edu) to estimate the relationship between the number of marked animals and the resulting confidence surrounding the estimate of overall detection efficiency. Given the relatively small number of birds that would be marked on any day, I assumed that each mark-recapture event was statistically independent of any other, and that it would be a very rare or non-existent event when more than one bird was marked at the same turbine on the same day. The resulting confidence curves in figures 1 & 2 below show clearly that a sample size of less than 40 marked birds would be sufficient for both small and large raptors to produce a biologically significant estimate at the 90% confidence interval (note that in the figures the confidence levels are ½ confidence levels – 0.025 being equivalent to alpha=0.05).

Figure 2. Statistical confidence in the overall detection efficiency estimate versus number of replicates for small raptors in a CJS mark-recapture design.



Fatality events are rare in the APWRA in relation to the number of turbines that are searched. Therefore, detecting 25-40 fatalities for any single species is not generally feasible. Golden Eagle fatalities cannot be included in the mark-recapture design because federal regulations require these carcasses must be removed upon discovery. The use of pigeons as surrogate species, should be avoided as well because there are questions regarding scavenger preference for these birds. Table 1 shows the average number of carcasses found per year by species based on the 2005-2007 data set which reflects an annual search of ~2500 active turbines. I assumed that most of these fatalities could be used as proxies for estimating the detection efficiencies associated with the four focal species currently being monitoring at APWRA, and that the results could be combined across species, but within size classes (i.e. larger versus small birds). In addition, I assumed that extra large and large bird sizes could be combined, provided that the more conservative estimates of scavenger and searcher efficiencies were used when estimating the necessary sample size.

Based on these previous surveys, an annual search of approximately 500 turbines by the QA/QC team should result in sufficient "marks" of 30-40 birds annually of each size class (60-80 birds total). The Sample Size software accounts for the error rate in recapturing birds when estimating the number of marks needed to estimate carcass "survival" (scavenger removal * searcher efficiency)(Lady et al, 2003). This survey could be compressed into a shorter time period, with additional turbines being searched (i.e. 750 turbines for 1/3 of the year), but seasonal variance in carcass finds should be considered. On average this design would yield approximately 44.7 marked raptors, of which 25.4 would be large raptors and the remaining 19.3 would be small raptors. Across all avian groups this survey effort would yield 31 large birds and 40 small birds.

The design could be built around the group which is supposedly most sensitive to theta based on scavenging issues which are small raptors. The same number of marks would be required if “small raptors” are used for the estimate of theta, versus “small birds”. To mark approximately 30 small raptors the QA/QC Team would need to monitor approximately 800 turbines, and would be provided with the opportunity to mark an additional 40.69 large raptors (~71 raptors total), or a total of 50 large birds and 64 small birds.

The use of “small raptors” versus “small birds” in the estimation of theta is a biological issue which revolves around the ornithology of each species – and is not statistical in nature. I am not sufficiently familiar with the logistics regarding field efforts to advise on the specific techniques associated with the design of this study, nor on the cost elements associated with its implementation. However, I do believe that the design is sufficiently robust from a statistical perspective that it should greatly improve the power of ongoing monitoring work. In addition the QA/QC effort might improve the overall number of carcasses detected annually within the ~2500 turbines in the current design due to the decreased survey interval at specific turbines and the increased number of searchers at turbines that receive the QA/QC deployment. I hope you find this statistical analysis useful when considering or developing a formal proposal or scope for a QA/QC effort in the APWRA.

Figure 3. Statistical confidence in the overall detection efficiency estimate versus number of replicates for large raptors in a CJS mark-recapture design.

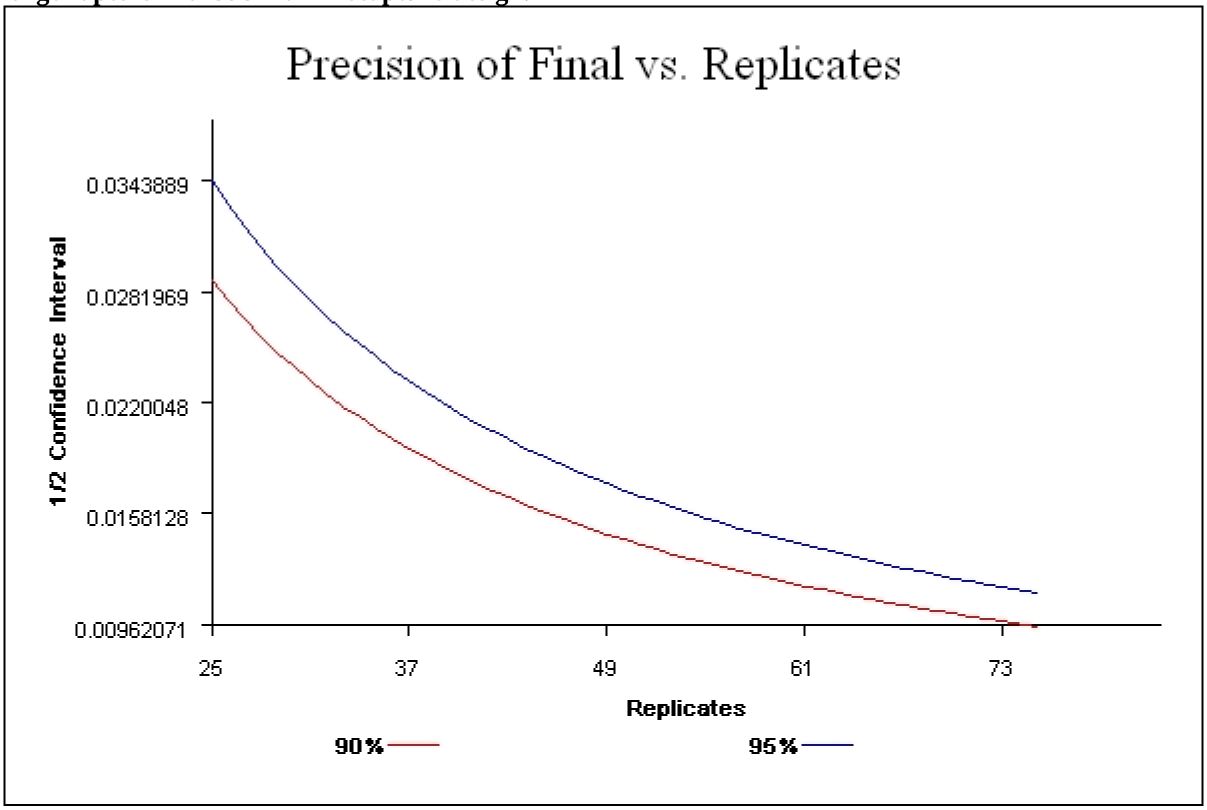


Table 1. Average fatalities found per year based on the 2005-2007 data set, and a search of approximately 2500 turbines every ~44 days.

Common Name	Bird Size	Average Fatalities Found	Average Fatilities Per Turbine
golden eagle	Excluded	12.33333	0.004933
turkey vulture	Extra Large	3.5	0.0014
wild turkey	Extra Large	2	0.0008
great blue heron	Extra Large	1	0.0004
great egret	Extra Large	1	0.0004
sandhill crane	Extra Large	1	0.0004
red-tailed hawk	Large	68	0.0272
barn owl	Large	34.66667	0.013867
great-horned owl	Large	10	0.004
common raven	Large	8.666667	0.003467
unidentified gull	Large	6.333333	0.002533
unidentified buteo	Large	6	0.0024

Common Name	Bird Size	Average Fatalities Found	Average Fatilities Per Turbine
unidentified large bird	Large	6	0.0024
northern harrier	Large	3	0.0012
American crow	Large	2	0.0008
black-necked stilt	Large	2	0.0008
California gull	Large	1	0.0004
ferruginous hawk	Large	1	0.0004
red-shouldered hawk	Large	1	0.0004
rock pigeon	Excluded	92.33333	0.036933
burrowing owl	Small	73.5	0.0294
western meadowlark	Small	66.66667	0.026667
American kestrel	Small	21	0.0084
unidentified dove	Excluded	10	0.004
mourning dove	Excluded	9.333333	0.003733
unidentified blackbird	Small	8	0.0032
Brewer's blackbird	Small	7.5	0.003
red-winged blackbird	Small	6.666667	0.002667
mallard	Small	4.333333	0.001733
killdeer	Small	2	0.0008
northern flicker	Small	2	0.0008
northern mockingbird	Small	2	0.0008
prairie falcon	Small	2	0.0008
Say's phoebe	Small	1	0.0004
Swainson's thrush	Small	1	0.0004
unidentified duck	Small	1	0.0004
western scrub-jay	Small	1	0.0004
western tanager	Small	1	0.0004

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