PROBLEM STATEMENT AND IMPLICATIONS: The U.S. Fish and Wildlife Service has a responsibility under the Endangered Species Act to protect species that are threatened or endangered with becoming extinct, and under the Bald and Golden Eagle Protection Act to protect eagles. Part of that involves issuing incidental take permits when activities are expected to result in the "take" of a listed species. To ensure compliance with incidental take permits, FWS needs a robust, defensible tool that can analyze whether the permitted level of take for listed species has been exceeded at a wind development site.

Current protocol for estimating bird and bat fatality at wind power facilities calls for searching designated plot areas below turbines to find carcasses of birds and bats killed by the turbines. To account for imperfect detection trials are conducted to estimate the proportion of carcasses that will remain unscavenged between searches and the proportion of those likely to be detected by a searcher. If only a fraction of the total turbines at a site is searched and if detection probabilities are much less than 1, then the overall probability of missing a carcass on the site can be quite high. The statistical tools we have for estimating actual fatality from observed carcasses are fairly robust when overall fatality levels are high. In many instances, however, such as with rare and endangered species, no or perhaps only few carcasses are observed. But no observed carcasses cannot necessarily be interpreted to mean no or even low numbers of dead individuals. Current research (Huso unpublished data) relates the overall probability of detection (combined probability of detection after accounting for unsearched areas, searcher abilities and scavenging) to the likelihood that 0 or more carcasses have actually been killed.

OBJECTIVES: The objectives of this study are 1) to develop the theoretical statistical framework that would allow inference regarding estimated take from observed carcasses and known search effort and detectability parameters; 2) to statistically evaluate the contribution, in terms of precision of estimates, of various components that are needed to estimate fatality at a wind power facility, namely the fraction of turbines searched, the interval with which they are searched, the searchable area within the designated search plot, and the number of trial carcasses used to estimate searcher efficiency and carcass persistence; 3) to develop software that resource managers as well as developers can use design fatality monitoring protocols to optimize for different objectives.

METHODS AND STUDY AREA: Unfortunately, as yet, there is no peer-reviewed method to ascertain whether the permitted take was exceeded. The statistical tools we have for estimating actual fatality from observed carcasses are fairly robust when overall fatality levels are high, even when detection rates are low, e.g. estimating fatality for general groups, such as all birds or bats. However, they are inadequate for estimating fatality from observed carcasses when none (or few) are found. It is easy to slip into the fallacy that no observed kills means no kills occurred. Interpretation of zero carcasses depends strongly on both the magnitude and the precision of our estimates of the probability of detecting a carcass (hence my first concern that the experiments proposed to estimate these factors have insufficient replication). We can observe 0 carcasses at a site for two reasons: 1) no animals were killed or 2) some animals were killed but we missed them in our searches. If our probability of detecting a carcass is high, then even if we find 0 carcasses, we can be relatively certain that either 0 or very few were actually killed. However, if our probability of detecting a carcass is low, then it is very possible that several animals were killed but we simply missed them in our searches. Ultimately, we can use

what we know about the search process and estimated detection probabilities to come up with a good idea of what the maximum kill likely was, even when none are observed.
I propose using a Bayesian approach that relies on either uninformative priors or combines prior information on potential take, e.g. from a modeling exercise such as that being developed at Patuxent, with observed information on detection rate parameters as well as observed carcass counts, to produce posterior credible intervals for estimated take. My work would allow managers or permit applicants to be able to make statements pre-construction like: "Given the stated search effort and assumed detection parameters, the proposed protocol assures that there is a less than 5% probability that excedence of the take limit, M, of Rare Species X will go undetected". It would also allow post-construction statements like: "Given the search effort and estimated overall detection probability=g, there is less than a 5% probability that actual take of Rare Species X exceeded the take limit, M, even though no carcasses were observed." I believe this would be useful to FWS in estimating the potential impacts of wind development on rare and endangered species, and in designing post-construction search protocols.

The software would be designed to provide different output depending on the needs of the resource managers. Pre-construction, one could set a value based on take permit for bat or eagle mortality that may not be exceeded and then explore parameters related to search effort, e.g. number of turbines searched or interval between searches, and detectability of carcasses, e.g. searcher efficiency, searchable plot area, carcass persistence time, to determine an optimal monitoring protocol that will provide the desired confidence that excedence of take will be detected if it occurs. Alternatively, post-construction, given the observed numbers of carcasses, the search effort and observed detection probability parameters, one could determine potential take.

Input values would include:

- Anticipated per-turbine fatality rate
- Anticipated range of per-turbine fatalities across the site
- Desired interval between searches
- Desired upper limit of confidence interval (UCL) of fatality (in multiples of estimate, e.g. 2X)
- Anticipated carcass persistence (CP) time and planned trial sample size *or* actual CP trial data
- Anticipated searcher efficiency (SE) and planned trial sample size *or* actual SE trial data
- Anticipated fraction of carcass density contained within search plots
- Total number of turbines at site

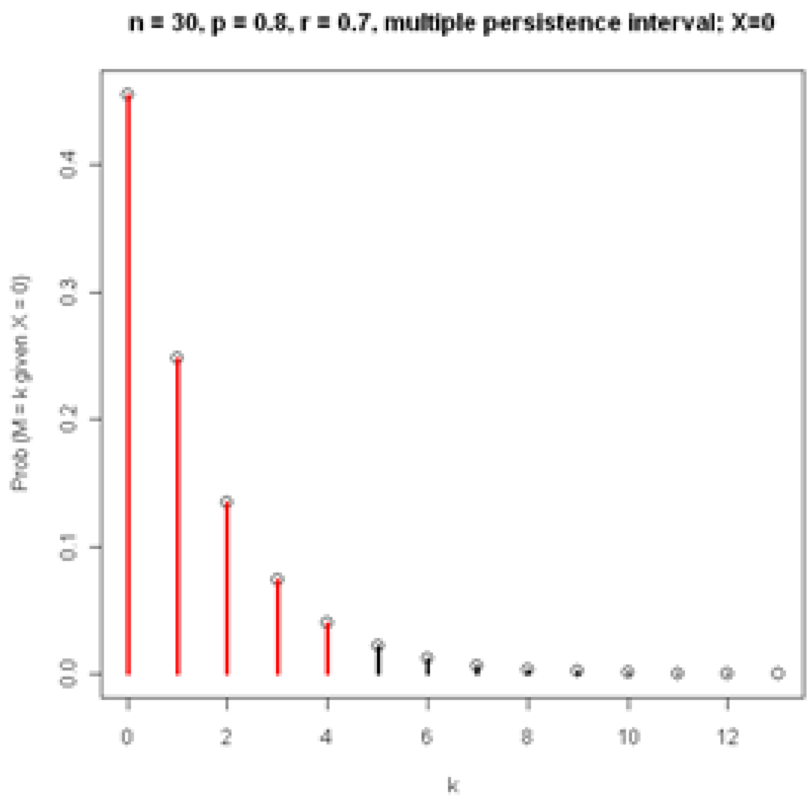
And output might be:

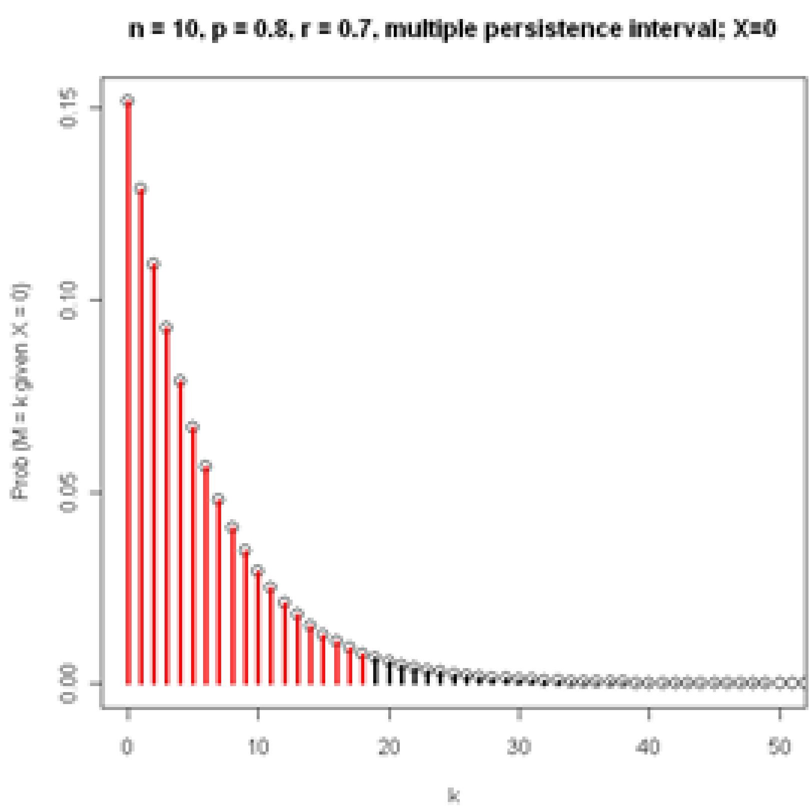
- Confidence (or credible) intervals: Estimated fatality given a certain number of observed carcasses, including 0
- Graphics: Holding all but two factors fixed, graph upper confidence (credible) limit as a function of other factors
- Tables: Multidimensional tables of trade-offs in precision when search intervals or sampling fraction or number of trial carcasses are changed

The examples below illustrate the results and potential graphical output from our proposed software to estimate take post-construction and illustrate the importance of designing a post-construction protocol that results in relatively high probability of detection (searcher efficiency, carcass persistence, sampling fraction all combined.)

The first example (left) is from a site with 40 turbines, from which a sample of 30 (75%) was searched weekly for 12 weeks. No carcasses of Rare Species X were found. The graph indicates that given an estimated searcher efficiency of 0.8, and probability of a carcass persisting for a week unscavenged of 0.7, there is a 45% chance that in fact 0 animals were actually taken, a 25% chance that 1 was taken, etc. Overall, there is a 95% chance that <4 were taken. The red lines indicate the values in the 95% credible interval, i.e. "There is less than a 5% probability that the actual take of Rare Species X exceeded **4**, given the search effort, the estimated detection probability and the fact that no carcasses were observed."

On the right is an example with the same conditions, except that a much smaller fraction of the turbines, only 10 of 40 turbines (25%) were searched. Now we can only say "There is less than a 5% probability that actual take of Rare Species X exceeded **18**, given the search effort, the estimated detection probability and the fact that no carcasses were observed."


n = 30, p = 0.8, r = 0.7, multiple persistence interval; X=0
Prob (M = k given X = 0)
0.0
0.1
0.2
0.3
0.4
0
2
4
6
8
10
12
k


n = 10, p = 0.8, r = 0.7, multiple persistence interval; X=0
Prob (M = k given X = 0)
0.00
0.05
0.10
0.15
0
10
20
30
40
50
k

Of course, this is only an example and results will change depending on prior information as well as input parameters from a particular study. In addition, refinements of most useful presentation of output will be determined in consultation with FWS representatives.

In order for resource managers to use the software we develop, webinars and workshops will be offered to instruct them in its proper use. For any new software tools we develop, we would plan on giving workshops that offer hands-on instruction in its proper and efficient use.

My work would result in 1) the theoretical statistical foundation that underlies inference regarding estimated take; 2) software that would allow managers to make statements like those above. The results of this research would be useful to managers in estimating the potential impacts of wind development on rare and endangered species, and in designing or evaluating proposed post-construction search protocols. Current agency needs focus on the Indiana bat, however the protocol developed to estimate take of an Indiana bat at a wind power will apply equally well to any species of concern, such as the Hawaiian hoary bat and golden eagles in low-density areas such as the California deserts. As these are statistical tools, when properly used, they can be applied at any wind farm in any geographic area to any species for which the expected fatality rate is low.