PROJECT TITLE: AN ANALYTICAL IMPACT ASSESSMENT FRAMEWORK FOR WILDLIFE TO INFORM THE SITING AND PERMITTING OF WIND ENERGY FACILITIES

DOE AWARD # EE0000525

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I would like to dedicate this report to Granger Hunt, a phenomenal speaker and consummate naturalist, and to the many talented authors whose work I had the privilege to reference in the bibliography and conceptual model. I would also like to thank the many participants sharing in the management of the Altamont Pass Wind Resource Area and Alameda County; from which I have learned more than I thought probable, and came to realize how little we sometimes know. I would like to acknowledge the patience and guidance of the Department of Energy staff (Office of Energy Efficiency and Renewable Energy grant EE-0000525) and ICF staff including Chris Brungardt, Doug Leslie, and Willis McConnaha. Each of them was presented with unfortunate, unduly, and unfair delays. Their patience and financial support made this analysis possible. I would like specifically acknowledge Brian Karas and Julie Yee for their tireless and brilliant contributions to the subject. Finally, I would like to thank Karl Dickman for his art – he is perhaps the most brilliant mathematician I have known, and I consider him the world's expert on the mathematical subjects addressed below.

Executive Summary

In the United States overall electrical generation capacity is expected to increase by 10-25 gigawatts (GW) per year to meet increases in demand (EIA, 2012 page 88). Wind energy is a key component of state and federal renewable energy standards, and central to the Department of Energy's (DOE) 20% by 2030 wind production goals (DOE, 2008). Increased wind energy development may present increased resource conflict with avian wildlife, and environmental permitting has been identified as a potential obstacle to expansion in the sector.

ICF developed an analytical framework to help applicants and agencies examine potential impacts in support of facility siting and permitting. A key objective of our work was to develop a framework that is scalable from the local to the national level, and one that is generalizable across the different scales at which biological communities operate – from local influences to meta-populations. The intent was to allow natural resource managers to estimate the cumulative impacts of turbine strikes and habitat changes on long-term population performance in the context of a species demography, genetic potential, and life history.

We developed three types of models based on our literature review and participation in the scientific review processes. First, the conceptual model was developed as a general description of the analytical framework (Appendix A). Second, we developed the analytical framework based on the relationships between concepts, and the functions presented in the scientific literature (Appendix B and C). Third, we constructed an application of the model by parameterizing the framework using data from and relevant to the Altamont Pass Wind Resource Area (APWRA), and an existing golden eagle population model. We developed managed source code, database create statements, and written documentation to allow for the reproduction of each phase of the analysis.

ICF identified a potential template adaptive management system in the form of the US Fish & Wildlife Service (USFWS) Adaptive Harvest Management (AHM) program, and developed recommendations for the structure and function of a similar wind-facility related program. We provided a straw-man implementation of the analytical framework based on assumptions for APWRA-wide golden eagle fatalities (ICF International, 2011, 2012, and 2013), and presented a statistical examination of the model performance (Appendix D).

APWRA-wide fatality rates appear substantial at all scales examined from the local APWRA population to the Bird Conservation Region. Documented fatality rates significantly influenced population performance in terms of non-territorial non-breeding birds. Breeder, Juvenile, Subadult, and Adult abundance were mostly unaffected by Baseline APWRA-wide fatality rates. However, increased variability in fatality rates would likely have impacts on long-term population performance, and would result in a substantially larger REA estimate.

We developed four recommendations for future study. First, we recommend establishment of concept experts through the existing system of non-profits, regulatory agencies, academia, and industry in the wind energy sector. Second, we recommend the development of a central or distributed shared data repository, and establish guidelines for data sharing and transparency. Third, we recommend development a forum and process for model selection at the local and national level. Last, we recommend experimental implementation of the prescribed system at broader scales, and refinement the expectations for modeling and adaptive management.

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Acronyms and Abbreviations

AHM	Adaptive Harvest Management
ANSI	American National Standards Institute
APLIC	Avian Power Line Interaction Committee
APWRA	Altamont Pass Wind Resource Area
AWEA	American Wind Energy Association
AWWI	American Wind Wildlife Institute
DOE	Department of Energy
GW	Gigawatt
HEA	Habitat Equivalency Analysis
Kg	Kilogram
MW	Megawatt
NOAA	National Oceanic and Atmospheric Administration
NWCC	National Wind Coordinating Collaborative
PVA	Population Viability Analysis
RAM	Random Access Memory
REA	Resource Equivalency Analysis
SQL	Standard Query Language
SRC	Scientific Review Committee
USFWS	United States Fish and Wildlife Service

Project Description

In the United States overall electrical generation capacity is expected to increase by 10-25 gigawatts (GW) per year to meet increases in demand (EIA, 2012 page 88). Wind energy is a key component of state and federal renewable energy standards, and central to the Department of Energy's (DOE) 20% by 2030 wind production goals (DOE, 2008). The wind energy sector must install capacity to keep pace with overall development and still achieve a 20% portfolio standard nationally. During the 3rd quarter of 2012 industry developed 1,833 megawatts (MW) across 15 states, bringing total wind energy installations to 4,728 MW (4.7 GW) for the year and 51.6 GW of total generating capacity for the nation (AWEA, 2012). While this substantial achievement represents a doubling of installed capacity since 2008, the rate of installation is below the 6 GW of installation expected for 2012, and far below the 10-15 GW of annual installed capacity (and total capacity of 305 GW) needed to achieve 20% wind energy production by 2030. This suggests that substantial barriers to wind energy development persist in the industry.

The environmental impacts of wind energy are considered small in comparison to most other sources of electricity, but include land use changes, carbon emissions, and wildlife impacts. Direct and indirect land use impacts are not negligible, and it is estimated that as much as 250,000 hectares of land will be needed to support the 305 GW of anticipated capacity (DOE, 2008). However, wind energy development is compatible with numerous other land use activities, and wind turbine land use impacts are considered very low in comparison with other sources of energy based on whole life-cycle analysis (Fthenakis, 2009). Similarly, although wind farm development and operations require the injection of resources, electricity generated from wind ranges between 14-33 metric tonnes per GW hour versus 974 metric tonnes per GW hour for coal (White, 2006). Although the nation-wide carbon benefits of wind energy development may not scale linearly with project-specific estimates, the overall environmental benefits of wind energy are well supported (e.g. Valentino, 2012).

These environmental advantages are central to the past and future successes of wind energy development. However, the potential impacts of wind turbines to birds and bats present a potential barrier to wind energy development. The presence and operation of wind turbines can reduce the availability of habitat, displace birds, or result in turbine-related collisions. These impacts may be mediated or exacerbated by the demographics, genetic potential, and life history of each species that is affected. On a national level these impacts must be considered within the context of the cumulative impacts of existing and proposed wind energy projects and other anthropogenic sources of mortality.

The direct impacts of turbine-related collisions have been previously summarized (e.g. Erickson et al, 2001, 2005, and Smallwood and Thelander, 2008). Several authors have presented methods and models for predicting (e.g. Tucker, 1996 and Eichhorn et al, 2012) and estimating (e.g. Smallwood, 2007, Smallwood et al, 2010, and Huso, 2010) turbine related fatalities. The US Fish & Wildlife Service (USFWS) describes an approach to addressing some of the issues related to impact prediction and estimates for eagles (USFWS, 2011). However, an overall framework for wind-wildlife interactions is lacking. DOE solicited proposals to reduce these barriers to wind energy development as part of its 20% by 2030 program.

To address these needs we worked to develop a scalable analytical framework for standardized assessment of long-term impacts of wind turbine operations on avian wildlife. A key objective of our work was to develop a framework that is scalable from the local to the national level, and one that is generalizable across the different scales at which biological communities operate – from local influences to meta-populations. The intent was to allow natural resource managers to estimate the cumulative impacts of turbine strikes and habitat changes on long-term population performance in the context of a species demography, genetic potential, and life history.

Our original intention was to develop the framework from the ground up through a collaborative process. Our initial review of the scientific landscape showed that efforts to address most elements of the wind energy wildlife problem were already underway, although a single unifying effort to bring together the various components was missing. Therefore we shifted our focus from trying to design individual elements of the framework, to designing and making transparent an overarching analytical framework. Similarly, we shifted our technique from organizing and hosting collaborations, to observing and participating in them. This allowed us to increase the scope and lengthen the schedule of our involvement without impacting our project budget, and to build upon best available science.

We developed the analytical framework in terms of a conceptual model, a description of the elements of the conceptual model, and an example of the framework based on the Altamont Pass Wind Resource Area (APWRA). Our goal was to develop a working model and a system for growing and adapting the model through time. The intention was to provide a straw-man and a system for refining the model to support the wind-wildlife adaptive management system. We did not intend to provide a final or complete model. Our benchmark was to adequately summarize the existing framework, to identifying areas for further development, and to provide the necessary computer software and data model for collaboratively improving the system. The purpose of our work was to develop a system that would ultimately be used to reduce applicant risk and the burden on regulatory agencies by providing both parties with a standardized analytical framework for permitting wind energy development in a scientifically and environmentally sound manner.

Project Background

"*If a model itself is a poor representation of reality, determining the sensitivity of an individual parameter in the model is a meaningless pursuit.*"

Pilkey and Pilkey-Jarvis, 2009 – page 25.

Scientists have studied bird collision risk for more than half a century to improve the aviation industry (see Solmon, 1970). Discussion of wind-turbine impacts on birds begin to emerge in the literature in the 1970's (see Rogers, 1975) as some of the first environmental compliance documents were being revealed and reviewed. In the earliest of examinations bird impacts were recognized as a potential legal barrier to the development of wind energy systems (Taubenfeld and Taubenfeld, 1976). The general problem is straightforward: birds can collide with turbines resulting in mortality and legal liability on the part of the owner-operator and other parties.

While the science took a somewhat different path in Europe, wildlife issues went mostly unexamined in the United States during the 1970's when initial deployments of first generation wind turbines were made. Monitoring of wind turbine impacts began to increase during the 1980s, but, even when documented, impacts from turbine collisions were generally dismissed as insignificant in comparison to other sources of mortality (see Byrne, 1983). During the same decade the scientific community began to examine the fundamental issues of the problem, and to position "*environment [as] central to the energy dilemma, not peripheral*" (Holdren et al, 1980, page 241).

The National Wind Coordinating Collaborative (NWCC) was formed in 1994 to open communication between industry and the scientific community to reduce barriers to commercial wind market development. A National Avian-Wind Power Planning Meeting, the first of its kind, was held July 20-12, 1994 in Lakewood Colorado under support of the NWCC collaborators. Although few solutions were presented at that initial meeting, all of the underlying questions of wind-wildlife impacts that we face today were presented in the proceedings in some form. Much has changed in the wind energy industry during the 18+ years since the meeting, and the questions brought forth by the collaborators seem prescient today. The participants were primarily concerned with the structural design of wind plants, how these might be sited or managed to reduce impacts, how to research and monitor impacts, and the underlying population biology which might influence the determination of significance.

Since those formative years the NWCC collaborators have been central to the furthering of wind turbine wildlife science. Over the past two decades bird mortality has been studied extensively at the Buffalo Ridge Wind Resource Area, Minnesota (Osborne et al, 2000, Johnson et al, 2002, Johnson et al, 2003, Leddy et al, 1999), and the Altamont Pass Wind Resource Area (APWRA) in California (Howell and DiDonato, 1991, Orloff and Flannery, 1992, Smallwood and Thelander, 2005, Smallwood and Thelander, 2007 and Barclay et al, 2007). These studies stemmed from and added to public scrutiny of the problem, were key to the establishment of an early management program in the APWRA (see Richard Curry Associates, 1997), and ultimately resulted in a long-term settlement agreement to collaboratively manage the APWRA for wildlife impacts (Golden Gate Audobon Society et al, 2007).

During the same period scientists worked to improve their understanding of wind turbine collisions as a process. Physical models of turbine collision risk were developed early on (Tucker, 1996). These were later expanded on in terms of the behavioral ecology of targeted species (Chamberlain et al, 2006, Kikuchi et al, 2008).

Despite the development of a relatively large body of scientific literature, limited progress has been made in the arena of improving collaborative adaptive management of wind-wildlife impacts. A Scientific Review Committee was established in the APWRA, and Technical Advisory Committees have been established elsewhere. USFWS put considerable resources into the development of guidelines and recommendations to address these issues for eagle conservation planning (USFWS, 2011).

As with the proceedings of the first National Avian-Wind Power Planning Meeting, the USFWS guidelines for eagle conservation planning discuss the range of elements needed to address wind-wildlife issues. Reference is made to wind turbine structure and siting, collision risk, adaptive management, mitigation, and population ecology. However, the question expressed by the NWCC collaborators remains: how can scientists and managers integrate estimates of collision risk with the fundamentals of population biology in a collaborative and adaptive manner?

Project Approach

"*It can scarcely be denied that the supreme goal of all theory is to make the irreducible basic elements as simple and as few as possible without having to surrender the adequate representation of a single datum of experience*."

Einstein (1933, page 165).

Our approach to the project generally followed the tasks we outlined in our original proposal. Specifically, we conducted a literature review, developed a web-based conceptual model, described the analytical framework, and developed an example of the analytical framework based on the APWRA. Our methods for communication and collaboration differed from those we intended to use in the project for adaptive reasons, and these deviations are identified below.

The conceptual framework was drafted based on a review of the relevant literature. We used key word search (i.e. Cambridge Scientific Abstracts), reference chaining (i.e. World of Science), Bayesian algorithms (i.e. Google Scholar) and established literature search techniques to develop a draft set of representations (variables and interrelationships).

Our original intention was to provide our literature review to the regulatory agencies, and industry to solicit contributions. However, during our literature review and initial communications it became evident that the key institutions, primarily NWCC, the American Wind Wildlife Institute (AWWI), and the US Fish and Wildlife Service, were engaged in their own efforts to assemble and disseminate key references (USFWS, 2009a, USFWS, 2011, and Strickland et al, 2011). We therefore asymmetrically re-structured our approach to integration with stakeholders with a focus on consumption of available information rather than reciprocation in the literature review process.

We summarized the occurrence and use of various representations (variables and interrelationships) in the literature set. We developed a written review of each variable and relationship for inclusion in the conceptual model. Our literature review was presented as a box-wire diagram at the VIII Wind-Wildlife Research Meeting on October 20th, 2010 in Lakewood, Colorado. We received substantial peer review and feedback at this early session.

We then began to develop the analytical framework in terms of a conceptual structure for analysis. The conceptual structure included the set of variables address turbine characteristics, operational plans, species biology & life history, collision risk, other sources of mortality, and habitat availability. The representations for each variable were defined using a set of hypotheses that describe the interrelationships of the variables.

Our original intent was to recruit a panel of experts to build a bridge between the literature review and the analytical framework. There were multiple factors that placed constraints on this component of the project. We found it difficult to recruit external concept experts to the review outside of submission to a technical journal. With no financial motivation, and constraints on time, we found it difficult to assemble a robust team during the development of the framework. More importantly we found that we were already involved in the key processes needed to effectively develop technical content. We found that our participation in the APWRA scientific review process, National Wind-Wildlife research meetings, and the California and Nevada Golden Eagle Working Group (GEWG) was sufficient to solicit and secure feedback from concept experts.

We developed three types of models based on our literature review and participation in the scientific review processes (Figure 1). First, the conceptual model was developed as a general description of the analytical framework. Second, we developed the analytical framework based on the relationships between concepts, and the functions presented in the scientific literature. Third, we constructed an application of the model by parameterizing the framework using data from and relevant to the APWRA. The approach to developing each model layer is discussed below.

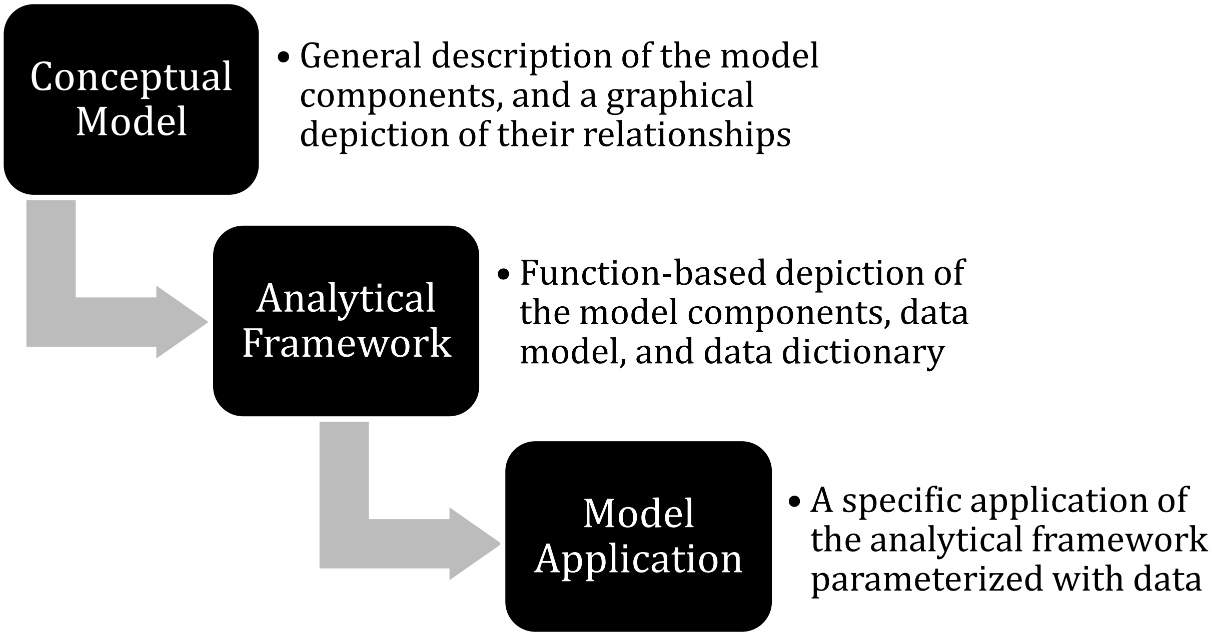
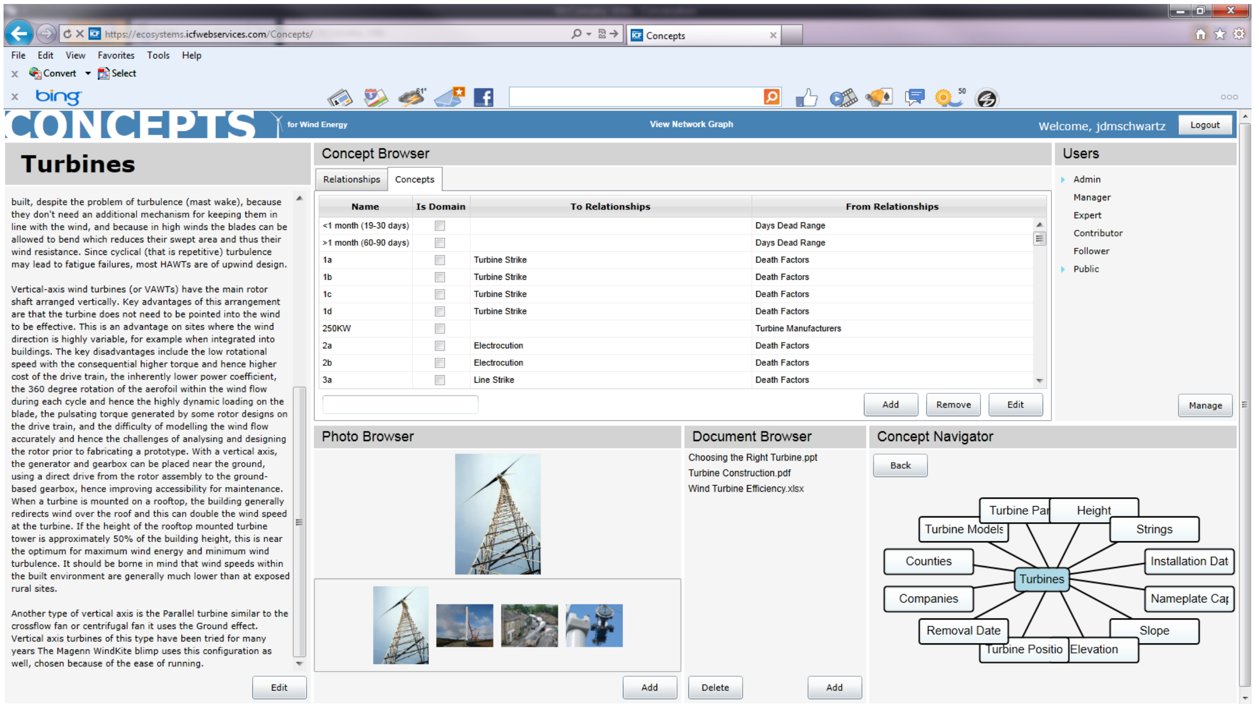


Figure 1. Relationship between the conceptual model, analytical framework, and the model application.

Conceptual Model

To assemble the conceptual model and provide a vehicle for peer review we developed an online conceptual model. We used a web-based toolkit to define the variables of interest and the relationships amongst them. We based our approach to model development and analysis on network-graph theory allowing us to describe the characteristics of sub-components of the model (see Newman, 2003, and van Steen, 2010).

To construct the conceptual model we defined each variable using a web application. The web application was designed as a password-protected secure interface that provides experts with permission to edit content in the area of expertise. The application allows concepts and relationships to be parameterized using multiple sources of information including the name and description of each concept, relationships among concepts, photos, and relevant literature (Figure 2). The web application is used to parameterize a relational database hosted in a Microsoft® SQL Server® environment. The relational database includes the data and meta-data defining the conceptual model, along with the documents and photos associated with each concept and relationship.



Turbines

built, despite the problem of turbulence (mast wake), because they don't need an additional mechanism for keeping them in line with the wind, and because in high winds the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since cyclical (that is repetitive) turbulence may lead to fatigue failures, most HAWTs are of upwind design.

Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically. Key advantages of this arrangement are that the turbine does not need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable, for example when integrated into buildings. The key disadvantages include the low rotational speed with the consequential higher torque and hence higher cost of the drive train, the inherently lower power coefficient, the 360 degree rotation of the aerofoil within the wind flow during each cycle and hence the highly dynamic loading on the blade, the pulsating torque generated by some rotor designs on the drive train, and the difficulty of modelling the wind flow accurately and hence the challenges of analysing and designing the rotor prior to fabricating a prototype. With a vertical axis, the generator and gearbox can be placed near the ground, using a direct drive from the rotor assembly to the ground-based gearbox, hence improving accessibility for maintenance. When a turbine is mounted on a rooftop, the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of the rooftop mounted turbine tower is approximately 50% of the building height, this is near the optimum for maximum wind energy and minimum wind turbulence. It should be borne in mind that wind speeds within the built environment are generally much lower than at exposed rural sites.

Another type of vertical axis is the Parallel turbine similar to the crossflow fan or centrifugal fan it uses the Ground effect. Vertical axis turbines of this type have been tried for many years The Magenn WindKite blimp uses this configuration as well, chosen because of the ease of running.

Concept Browser

Relationships | Concepts

Name	Is Domain	To Relationships	From Relationships
<1 month (19-30 days)	☐		Days Dead Range
>1 month (60-90 days)	☐		Days Dead Range
1a	☐	Turbine Strike	Death Factors
1b	☐	Turbine Strike	Death Factors
1c	☐	Turbine Strike	Death Factors
1d	☐	Turbine Strike	Death Factors
250KW	☐		Turbine Manufacturers
2a	☐	Electrocution	Death Factors
2b	☐	Electrocution	Death Factors
3a	☐	Line Strike	Death Factors

Users

- Admin
- Manager
- Expert
- Contributor
- Follower
- Public

Photo Browser

Document Browser

Choosing the Right Turbine.ppt
Turbine Construction.pdf
Wind Turbine Efficiency.xlsx

Concept Navigator

Figure 2. Screen capture of the wind-wildlife conceptual model web interface.

The interface includes seven panels for managing information in the model. The controls include tab controls to input and edit concepts (nodes) and relationships between concepts (edges). Concepts are created as nodes, and then related to each other using edges. In addition there are controls for parameterizing nodes and edges using narrative, photos, and documents. The interface includes a navigation panel that displays the proximate concepts (i.e. nodes that are directly connected to the selected node), and allows experts to move from one node to another to explore relationships while they parameterize the model. Finally, there is a panel which allows project administrators to manage users and permissions to provide control over the model information.

The current conceptual model can be viewed in its entirety online (ecosystems.icfwebservices.com/Concepts/Graph/Viewer.html). In addition, users can navigate each of the concepts and relationships using the web application (ecosystems.icfwebservices.com/Concepts/). Although the descriptions of the conceptual model included in this report are useful, the most robust approach for examining the conceptual model is to utilize the functionality of the web application, and readers are encouraged to make use of that resource.

To visualize, organize, and explore the characteristics of the conceptual model we used the Gephi open source application programming interface (Bastian et al, 2009). We used a force-directed algorithm that strives for uniform edge lengths between concepts to develop the initial layout of the model (Fruchterman and Reingold, 1991). We then modified the overall graph to maximize readability of the graph, and to minimize overlap between concepts (Figure 3).

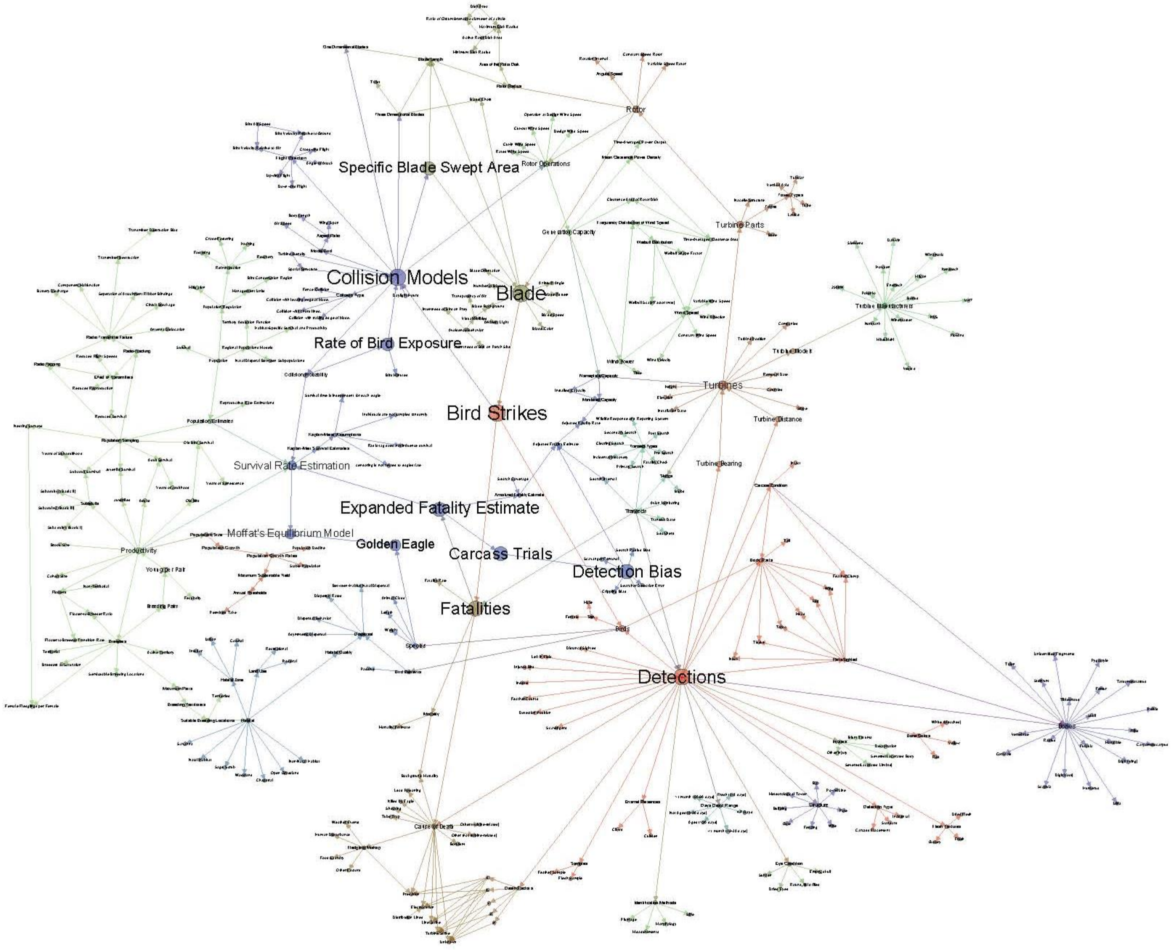


Figure 3. Full network graph of the wind-wildlife conceptual model.

It is difficult to describe the model in using narrative because of its complexity and multi-dimensionality. This difficulty can be reduced by dividing the model into domains of closely related concepts. To help find groups of concepts within the overall model structure that would be useful domains, we used an heuristic called "*betweenness centrality*" (Freeman, 1977).

Equation 1. Formula for estimating betweenness centrality to create information domains

$$g(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}$$

Where betweenness centrality for a node, $\boldsymbol{g(v)}$, is the sum of $\boldsymbol{\sigma_{st}}$, the total number of shortest paths from node $\boldsymbol{s}$ to node $\boldsymbol{t}$, divided into $\boldsymbol{\sigma_{st}(v)}$, the number of those paths that pass through node $\boldsymbol{v}$.

Betweenness Centrality was used in Gephi to determine node size. It is a numerical value that is computed for each node and in our case the larger the value the bigger the node. Node Betweenness Centrality measures how often a node appears on shortest paths between nodes in the network. It does good job at identifying key concepts in the network and mapping the value to node size provides the viewer with more context for the data.

Betweenness centrality provides an estimate of the importance of each concept based on the number of connections between a concept and all other concepts to which it is connected. The concepts were ranked according to their betweenness centrality, and the top ten were selected as the organizing information domains for presentation of the conceptual model. In addition we reviewed several descriptive statistics to ensure that the core information domains were selected.

The network characteristics of the ten domains are presented below along with their corresponding descriptive statistics (Table 1). Descriptive statistics included the network diameter, graph density, modularity, clustering, and average path length of each domain (sub graph) in the model. Refer to Diestel (2005) for the functions used to generate the remaining statistics.

The average degree for each concept node was calculated as the average of the simple degree of all connected nodes. The simple degree of each concept node was calculated in terms of the number of edges connected to each concept node. The average degree provides an estimate of the complexity of the nodes connected to the concept node in question.

The graph diameter provides an estimate of the size of each sub graph or concept domain. Graph diameter was calculated in terms of the longest shortest path, or the average distance of the farthest node from the concept node in question. Larger values represent larger graphs in terms of the number of concepts connected to the node in question. Larger graphs have the potential to be more complex and to contain more connections between concepts. However, smaller graphs may contain many concepts and many connections as well, so graph diameter must be considered in the context of the other graph metrics.

Graph density was calculated to provide an additional estimate of the complexity of each sub graph or concept domain. Dense graphs have a larger number of relationships between concepts relative to simpler network graphs with a similar number of concepts in them. The distinction between more and less dense graphs is contextual in that it is influenced by the number of concepts, the number of relationships, and the level of connectivity between them.

Modularity was estimated for each concept node to provide an estimate of the structure of each sub graph. For each concept node there are collections of concepts where many lower degree concepts are developed to describe a higher level concept. Modularity is the fraction of relationships within a sub graph compared to the fraction of relationships that would be within a sub graph if the model was assembled randomly. Sub graphs with high modularity have a high level of connection within the sub graph, but a low level of connectivity outside of the sub graph.

A clustering coefficient and average path length were calculated to provide descriptions of the shape of each sub graph. The clustering coefficient provides a measure of how tightly concepts are clustered together. The average path length provides an estimate of the distance between concepts within each sub graph. Together with graph density and modularity, these descriptive statistics help users evaluate the general complexity of each sub graph.

Table 1. Information domains of the conceptual model and their descriptive statistics.

	Collision Models	Detections	Expanded Fatality Estimate	Fatalities	Habitat	Population Estimate	Productivity	Rotor Operations	Turbines	Transects
Betweenness Centrality	4874	4690	3940	4329	140	300	931	782	287	2062
Average Degree	1.08	1.113	1.036	1.5	0.957	0.941	1.155	1.136	1.042	0.933
Graph Diameter	6	5	10	6	6	5	13	6	10	4
Graph Density	0.09	0.023	0.077	0.103	0.087	0.118	0.04	0.108	0.03	0.133
Modularity	0.61	0.711	0.622	0.446	0.56	0.561	0.635	0.486	0.74	0.406
Average Clustering	0.284	0.038	0.156	0.015	0	0	0	0	0.051	0
Average Path Length	3.07	3.312	4.743	2.664	3.099	3.088	4.823	3.095	5.133	2.362

Descriptive statistics alone do not explain the problem being addressed by each sub graph. However, they do provide some insight into the complexity of the information system that has been developed to address the questions posed in each domain. Collision modeling is shown as the area of highest information complexity, and issues surrounding collision modeling can be found throughout the literature (see below). The remaining complexity exists around the estimation of potential impacts from wind turbines in terms of the transects used to monitor fatalities, the detections of fatalities that are made, and the estimation of fatalities based on this monitoring.

The observed patterns of information complexity are biased by the level of development of the data model in each area, and are mirrored in the scientific literature. Scientists monitoring wind farms and those responsible for planning and permitting have put considerable attention into collision modeling and monitoring. Conversely, the relationship between habitat and fatalities has been poorly studied, resulting in a relatively sparse information domain.

One cannot discern, on these model concepts alone, the extent to which information quality will influence the planning and permitting process. Those outcomes must be evaluated based on the performance of the analytical framework. However, in reviewing the model sub graphs we encourage the reader to consider the context of the information landscape developed for each domain. Below we provide a general description of each of the conceptual domains, a definition of each concept, and references to the sources used in the development of the analytical framework. As with our overall analysis, we present each sub graph of each conceptual domain as a straw man framework for future development. Some of the information areas are highly developed and have received extensive peer review, whereas others represent our best assessment of the available literature. The latter will likely evolve in the near future as applicants move forward in the permitting and planning process. We believe the sub graphs will be useful for continuing the conversation between agencies and applicants, and will reduce barriers to permitting and planning by providing a structure around which the information structure for each domain can be developed in the future.

Concept Domains

The information landscape for planning and permitting of wind energy facilities is relatively complex. We simplified the information landscape by parsing the conceptual model into ten sub graphs or concept domains. Within the full conceptual model each concept domain is connected to the next via one or multiple relationships, each of which has been collapsed into a single relationship to describe the overall structure of the model (Figure 4).

Below we describe each concept domain in alphabetical order. We provide definitions for the concept members of each domain, and provide references for the sources used to construct the analytical framework from the conceptual model. Due to differences in the availability of information for each concept and concept domain, we treated each area of information differently. We gave more attention to areas of greater complexity and with more available information than to less complex concepts or concepts for which little information is available.

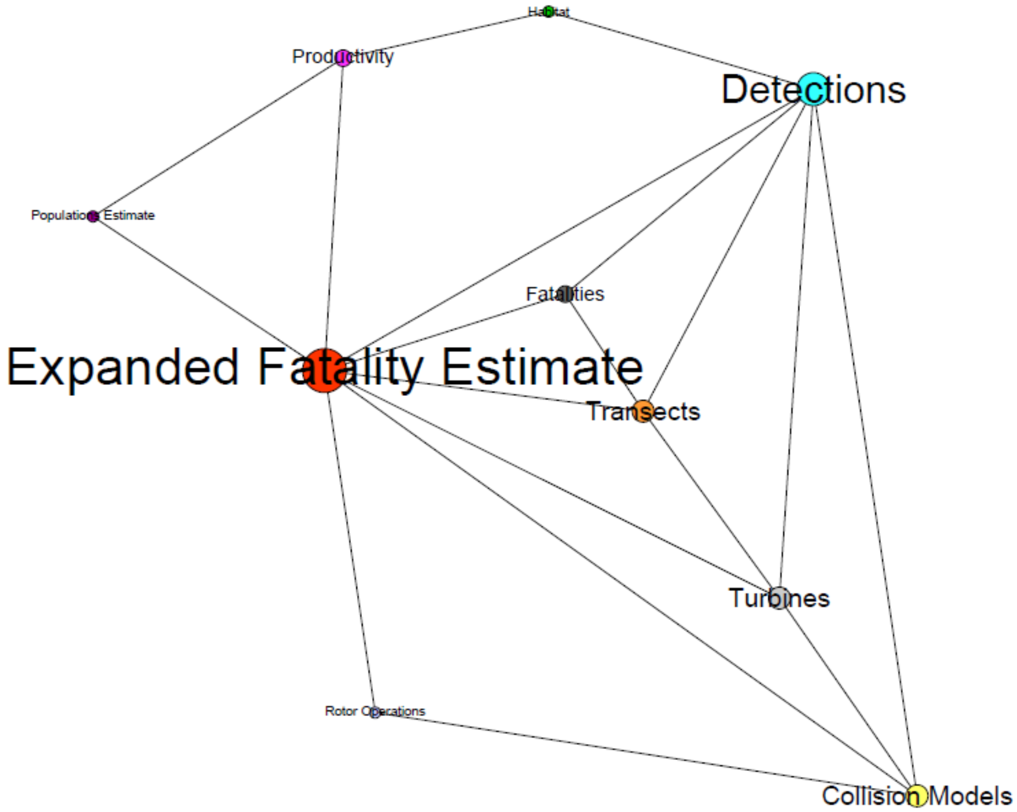


Figure 4. Information domains addressed in the wind-wildlife conceptual model.

Project Products and Technology

We describe an analytical framework for the assessment of wind energy impacts to avian wildlife. The framework consists of a series of models that address individual elements of the problem statement. The individual models are somewhat independent, but share an underlying information structure and organizing concepts (e.g. Edwards and Steins, 1998). In concert the models build on the concepts defined above, and provide a workflow to assess the problem statement in a broad sense.

The framework emerged from previously published literature and ongoing efforts to evaluate impacts. The general application of the framework was greatly influenced by identification of eagle issues in central California (Hunt, 1998 and 2002, and Smallwood and Thelander, 2004 and 2005), recommendations for the development of Eagle Conservation Plans (USFWS, 2011), and work to assess and monitor eagle issues in the APWRA (e.g. Smallwood, 2007, and ICF International, 2009, 2010, 2011, 2012, and 2013). Theoretically the framework can be applied to any wind-wildlife system, but the elements themselves were evaluated specifically against the requirements for golden eagles in the APWRA.

The description and application of this analytical framework was assembled to provide an approach that can address the wind-wildlife concepts at the national level. Although the overall approach is not new, the methods of analysis are more specific than the general recommendations of the USFWS (Figure 5). We present the theory, assumptions, and mathematical approach to the management of wind-wildlife data (Data Model), the estimation of risk (Collision Risk), the evaluation of cumulative impacts (Moffett's Equilibrium Model), and the assessment of mitigation requirements (Resource Equivalency Analysis). We provide methods for evaluating performance of the system, and make recommendations for future work. Our assessment of the applied framework was limited to the application to golden eagles in the APWRA to provide a specific example of the performance and utility of the approach.

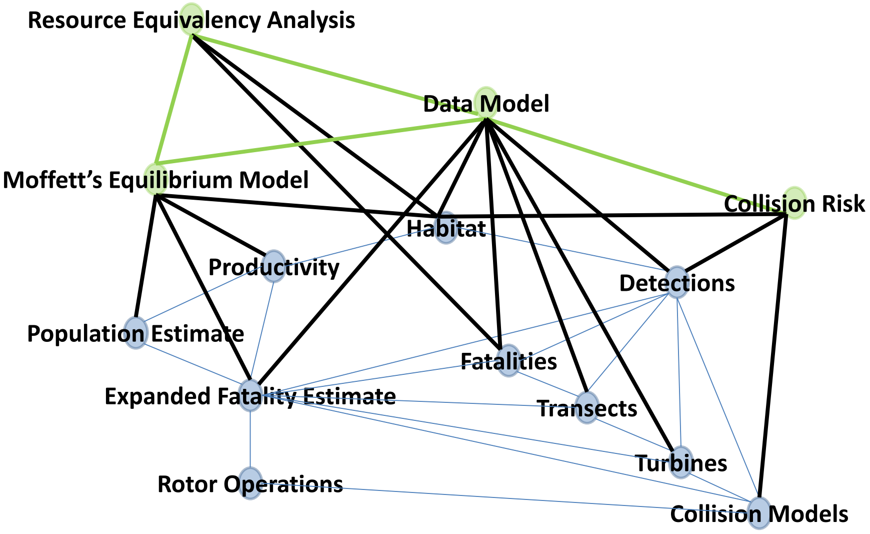


Figure 5. Elements of the analytical framework, and relationships to the conceptual model.

There are many other models that could potentially satisfy the analysis, and the abilities and limitations of some of these are referenced in their analogous sections below. Huso (2010) developed a software application for estimating fatality rates which includes an implied data model and system for integrating fatality and wind turbine information. The application has been positively reviewed in the scientifically literature, and the approach has utility that is not ignored in our description of the selected framework. However, the work of Huso was not selected for the application of the framework due to the partial definition of the underlying data model, and the potential difficulties of scaling the approach to broader scales. In other regards the techniques of Huso are equal to or superior to the selected approach, and these should be considered with considerable regard in subsequent phases of development.

Similarly, work by the USFWS (USFWS, 2011, and Farmer and Nagy, 2012) has much to offer the problem. This work offers a system for estimating pre-construction impacts, and includes a Bayesian mechanism for integrating pre-construction bird use to inform post-construction fatality results. The underlying permitting approach (USFWS, 2009b) is agnostic to the methods of assessing risk, does not include an explicit data model, and only loosely addresses the full suite of questions raised by population biologists (Milsap and Allen, 2006). The selected analytical framework generally conforms to the recommendations of USFWS and their permitting rule, but includes a revised approach that is more explicit and scalable at some steps. In other regards the work of USFWS is very similar to the selected framework, and must be credited with outlying the general elements of the problem.

Model Description and Key Assumptions

Data Model

The purpose of the analytical framework is to support permitting, planning, and operations at the national level by supporting the assessment of impacts and mitigation requirements. Before modeling of project or cumulative impacts can be conducted, information describing turbines, fatalities, and target species must be assembled in a data model. A central data model, or a series of interconnected models, provides a common information system upon which data can be stored, managed, and accessed by the various parties involved in the modeling of impacts and mitigation. Central data systems have already been developed to address wind-wildlife literature (Sinclair et al, 2009), land cover (Homer et al, 2007), and bird use (O'connell and Gilbert, 2006). Commercial and propriety databases have been developed by the wind energy industry, but a publicly available data model for compiling and managing wind-wildlife information has yet to be deployed1.

In theory the data model may be of any quality or nature. In practice the model has certain requirements to support implementation due to the migratory nature of birds, the national scope of wind energy wildlife impacts, and the interdisciplinary context of the impact assessment. The NWCC, AWWI, and APWRA SRC have extensively reviewed the wind wildlife problem statement, and defined the context of the problem statement. In this context of the national wind wildlife problem the data model must be explicit (i.e. clearly stated so it can be reviewed and reproduced), normalized (i.e. formed so that information from multiple sources can be integrated), and scalable

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[1] The American Wind Wildlife Institute (AWWI) is developing a pilot Research Information System that is due to be deployed soon.

from the local to the national level. We selected the data model based on the technical and adaptive requirements defined by the review groups.

The most extensive and technically reviewed effort to create a common SQL data model to address wind-wildlife issues can be found in the APWRA SQL database developed for Alameda County (ICF International, 2011, 2012 and 2013). The system was developed to address mathematical and statistical questions raised in a settlement agreement regarding ongoing operations of the APWRA wind energy resources (Alameda County, 2007). The database is unique in that it contains information describing turbines, searches of turbines to detect turbine-related fatalities under the APWRA monitoring program, and the results of that monitoring in the form of one or multiple detections of fatalities. In addition the data model includes the functions necessary to calculate or consume collision risk estimates as discussed below. Although the APWRA data model was developed using Microsoft® Structured Query Language (SQL), the approach is agnostic to the specific SQL language used, and could be replicated in any SQL development environment with sufficient refactoring.

Based on the contribution of subject matter experts, we selected the APWRA SQL data model for the analytical framework. SQL is a language that was created for the construction and management of relational databases. Microsoft®, Oracle®, and MySQL™ all maintain SQL libraries and systems to develop and implement SQL databases. SQL data models are often selected for building scientific models because developers generally follow a shared standard under the American National Standards Institute (ANSI), the International Organization for Standards (ISO), and the International Electrotechnical Commission (IEC) under joint committee (ANSI/ISO/IEC, 1999).

SQL offers numerous advantages over other data modeling systems. SQL is extensible and customizable, while at the same time the SQL modeling environment requires a certain level of conformity to the shared standard. Similarly, SQL does not require well-formed or normalized data models, but when constructed these models can be expressed in an explicit fashion. Another advantage is that data models created using the SQL standard can be generated in a desktop or server environment, and then scaled to shared or distributed systems if best practices are employed. While Huso (2010) and USFWS (2011), and their techniques for collision risk assessment may provide reliable estimates, the APWRA data model provides an example of an estimate developed using an explicit data model which had advantages in terms of scalability and reproducibility.

The APWRA data model was developed under the nexus of Alameda County in collaboration between the APWRA Scientific Review Committee (SRC), stakeholders, state and federal regulatory agencies, Alameda County, and industry over a five year period from 2007 to 2012. The SQL Data Model includes SQL statements contained within classes that are used for data definition and data manipulation. The data definition statements define the tables and fields needed to create, view, and store the underlying data, whereas the data manipulation statements are used to add, update, or delete information.

In practice the definition and manipulation statements are used concurrently in the SQL classes that make up the data model. The initial design was inherited from consultants working in the APWRA (Smallwood and Thelander, 2005) developed in Microsoft® Excel® and Access®. These initial products contained baseline[2] information that did not conform to the requirements of a relational database (Codd, 1970), and were used for their content only.

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[2] We use the term “baseline” to be consistent with foundational literature in the APWRA (Smallwood, multiple entries), which is opposite of most permitting systems.

The baseline information was imported into an empty Microsoft® SQL Server database to begin development of the SQL Data Model. Existing data was normalized and used to create a relational data model in several steps. These steps followed the 1st, 2nd, and 3rd forms of normalization (Codd, 1971).

The 1st form of normalization was used to refactor data tables and content describing turbines, searches, and fatalities so that each value contained in each record in each table contained one and only one value and could be considered atomic. This revision was applied to reduce the possibility of duplicate records, and is a prerequisite of building mathematically sound relational databases (Codd, 1971). Null values were allowed to persist where appropriate under Codd's null-value exception to the 1st normal form (Codd, 1990). In addition the notes field of each table was not normalized to allow this documentation to persist, but there are no dependencies on the notes in the data model.

Normalization under the 1st form resulted in the disaggregation of some elements of the turbines, searches, and fatalities information. For example the data declaring groups of turbines as strings of turbines was brought into a separate table declaring strings. Similarly, species identified in the fatality data was refactored into a separate table declaring species. These improvements were implemented to allow for further normalization of the data, and to prepare the system for relational modeling. The 2nd form of normalization was applied to the refactored tables to create candidate keys upon which relationships could be declared (Codd, 1971). To ensure that the system was scalable and could be deployed in a distributed computing environment a 128-bit Universally Unique Identifier (UUID) was selected as the candidate key for each table, and was populated using the Microsoft® Globally Unique Identifier (GUID) methods (Kagle and Odinak, 2007, and Microsoft, 2012). This ensured that each record in each table could be discriminated against all others, and that data added to the database could be included without the risk of redundancy or the loss of information.

The 3rd form of normalization was used to reduce transitive dependencies within and between each data table. A transitive dependency occurs within a tables when changes to one or more attributes within a table results in inconsistencies in other attributes in the table due to a poorly formed relationship to the candidate key established under the 2nd form of normalization (Codd, 1971). These were reduced by evaluating the dependency of each attribute on all others within each table in the database, and creating the appropriate tables for holding these elements. The resulting tables underlying the APWRA database are similar to the concepts defined in the conceptual model. These include tables of turbines, strings, collections of strings, searches, searchers, species, detections, and fatalities and their corresponding attributes (Appendix A).

After applying the 1st, 2nd, and 3rd forms of normalization the APWRA database was considered ready for the establishment of relationships (Date, 2003). The initial description of the data model was delivered in a written record, and presented to the SRC (Schwartz et al, 2009). The APWRA SRC, Monitoring Team, and collaborators worked iteratively over the course of several years to develop relationships within the data model that support query of the data in a defensible and replicable manner. The process included review, suggested revisions, and testing. Documentation of the development was made in the various reports, memoranda, and meeting minutes for the APWRA SRC (**www.altamontsrc.org**).

The model was considered resolved once the information from the contributing tables could be queried and joined across tables using relationships to their primary keys without the production of inconsistencies, redundancies, or errors in the outputs. The current data model provides the necessary tables for bringing together information regarding turbines, fatalities, and target species. Despite issues with the underlying data in the APWRA that have been noted in the record, the data model itself has held up to peer review, and its utility has been repeatedly demonstrated in the APWRA.

The statements for creating the peer-reviewed model can be found in Appendix B, and a diagram of the corresponding tables can be found in Appendix C. The current model includes records of 5,498 turbines, 29,312 searches, 10,870 detections on 8,295 fatalities, and 10,578 bird use sessions in the APWRA. In its current form the data model could be applied to other systems or species including those affected by off-shore facilities. The spatial hierarchy in the data model will allow it to be scaled to the national level with minimal refactoring. The hierarchy, based on a GIS Base Layer of Operating Group Boundaries (BLOBs), allows for information to be compiled at fine scales, and aggregated to any higher level. The model was selected as a useful example of scalable model that integrates across the necessary concepts, and was used in producing the results from the analytical framework presented below.

Collision Risk

A number of methods for estimating collision risk have been developed in the past. Collisions can be estimated based on modeled outputs, empirical observations, or using both modeled and empirical information. Each of these approaches has different methods, assumptions, benefits and limitations. Summaries of collision issues (e.g. Erickson et al, 2001, Drewitt and Langston, 2008, and Smallwood, 2005) have not resulted in a prescription for evaluating risk that has satisfied both biologists and regulators. However, consensus has been reached, as can be seen across the literature referenced below, in regards to the use of fatalities per MW of installed nameplate capacity per year as the underlying performance metric for estimating total fatalities at wind energy facilities.

Tucker (1996) described the issue based on physics and geometry in terms of a bird moving through a rotor swept space. The basic assumptions of Tucker’s model are sound, and bring together the essential components of the vector of bird flight, wingspan, duration of exposure to the rotor swept area, aspect of the turbine blades to the wind, turbine tower height, blade length, etc. However, the approach has failed to gain traction in the scientific community due to its apparent oversimplification of turbine collisions as a mostly physical process. In short, the model is not complex enough to be scaled to a wind energy farm (or multiple facilities) because it fails to take into account the behavioral ecology of impacted species, the different scales at which birds and turbines operate, and the geographical complexity of real-world wind energy facilities. There are few examples of Tucker’s model providing reliable estimates of wind energy facility collision risk post-construction, and there is little support in the scientific or regulatory communities for a purely physical model of turbine-related collisions that ignores their ecology.

The behavioral ecology of birds has been incorporated in collision modeling due to its potential influence on collision risk based on first principles. If a species is completely absent from a facility, or completely avoids turbines, than its potential for collision is zero. However, above zero risk the problem becomes more complex.

Avoidance of turbines has been hypothesized and supported in the scientific literature (Chamberlain et al, 2006, Whitfield, 2009, and Whitfield and Madders, 2006). The possibility of density independent risk has been raised as well (Lucas et al, 2008). The literature and conceptual model seem to concur that the behavioral ecology of a species will result in a complex pattern of attraction to resources in open habitat, and partial avoidance of turbines (Kikuchi, 2008). Eichhorn et al (2012) developed a more comprehensive model based approach that brings together models of behavioral ecology with the physical descriptions of the turbine field. Despite these advances, consensus has not been reached for the application of purely modeled based approaches to collision risk estimation.

The draft approach to ECP development recommends integration of modeled estimates with empirical data using a Bayesian approach (USFWS, 2011). This approach appears promising in part because it allows for the best use of all available information. However, the modeled estimates are still dependent upon all of the model assumptions, and the empirical contributions are limited by the quality and quantity of available empirical information. The regulations of USFWS are agnostic to the specific collision risk modeling methods, and the current documentation and methods behind the USFWS model are still under development. In time, perhaps soon, the scientific and regulatory communities may develop consensus around the modeling methods for estimating pre-construction collision risk. In the future these estimates can be consumed by the existing analytical framework, and will be necessary when assessing impacts at new facilities.

To support the development of the analytical framework described in this report we selected a mostly empirical based approach to estimating collision risk. The advantages of using empirically-derived estimates is that this approach avoids the issues surrounding physical modeling and Bayesian statistics that are currently unresolved in the scientific literature, and that it provides the framework with a deterministic estimate which can be re-produced based on a given set of inputs and assumptions.

For existing facilities, such as the APWRA, empirically based estimates may be sufficient for estimating future fatality rates if certain assumptions are met. Most notably, the impacts of future turbine conditions must be assumed or modeled using comparative analysis or some understanding of the underlying collision risk factors (see Orloff and Flannery, 1992). The APWRA includes older generation turbine models with a current level of risk, and plans for repowering the system with newer generation turbines that have an assumed lower level of risk. Despite some uncertainty regarding the precise number of fatalities that would actually occur in a repowered APWRA, the use of empirically-derived fatality estimates is justified in this case.

Byrne (1983) described a general approach to collecting empirical data to support an assessment. The process, shared by many other authors, involves surveying an area around the turbine at known intervals and documenting the observed fatalities. Byrne did not adjust detections for missed evidence, and did not attempt to generate an annual fatality rate estimate. Smallwood (2007) provides a summary and specific example for estimating collision risk based on empirical data which incorporates imperfect detection (see Horvitz and Thompson, 1952). The approach requires an estimate of detection probability which can be populated using data from other systems or systematic studies of detection probability at the facility in question (Huso, 2010, Smallwood, 2007 and 2010, and ICF International, 2013).

During 2010 through 2012 the APWRA data model was extended to include a series of equations, developed in Microsoft® SQL, to produce estimates of collision risk based on fatalities per MW per year, and estimates of total fatalities through time. The series of statements and equations, included in Appendix B, can be used to generate estimates from monitoring data based on known search dates, detections, fatalities, and estimates of detection probability. The APWRA example includes estimates of fatality rates under different turbine conditions across space, and changing turbine conditions through time. In the APWRA model bird use is included as a covariate, but is not an input to fatality rate estimation.

The most recent application of the model incorporated the results of systematic surveys of detection probability in situ. In addition, the spatial hierarchy of the model is such that estimates of fatality rates from other sources can be incorporated. The current system relies upon estimates from monitoring data for areas within Alameda County which makes up the majority of the APWRA, and estimates from other models and monitoring programs in Contra Costa County. Both the data model and collision risk model are expressed in the same source code, although other configurations are possible. The inclusion of detection probabilities from other sources is possible, and comparative analyses of various assumptions regarding detection probability have been presented (ICF International, 2012).

Based on the assumptions defined in the most recent report, the three-year estimate of APWRA-wide golden eagle fatalities ranged from 0.07-0.11 fatalities per MW per year across five three-year periods. This corresponds with a three year average collision risk of 38-68 golden eagles per year for the existing configuration of turbines. The estimate for the most recent three year period was 0.08 fatalities per MW, or 55 fatalities per year with a 95% confidence interval of 52-58 fatalities. In contrast, fatality rates for repowered sites within the APWRA are considerably lower, and range from 0.01 to 0.04 fatalities per MW per year. Under a repowered scenario of 580 MW of installed capacity, this corresponds with a total estimate of 6-23 fatalities per year, or less than half of the current APWRA-wide estimate. For purposes of designing and testing the analytical framework, we selected the APWRA-wide estimates of golden eagle fatality rates generated by the APWRA model. Other sources of collision risk estimates are possible, and these could be incorporated in future analyses without modification of the underlying framework.

Moffat's Equilibrium Model

Wind energy facilities directly and indirectly impact avian wildlife (e.g. ICF International, 2012). Indirect impacts occur due to reductions in habitat quantity or quality from turbine footprints and operations. Direct impacts occur from turbine-related collisions, or other injuries and fatalities directly related to the installation and operation of wind turbines. So called "*turbine-related*" impacts are direct. These include collision with other structures due to turbine avoidance, collision with maintenance vehicles, and other sources of directly measurable harm associated with a wind energy facility.

The impacts of wind energy facilities occur in real space and time, and influence members of a biological population. Collision risk provides a probability of direct impacts, but does not define its context. "*The life cycle is the fundamental unit of description of the organism*" (Caswell, 2001 page 1). The application of population biology is required for the analysis of wind facility impacts because the life cycle provides a unifying theory for integrating collision risk with other aspects of the ecosystem. Population biologists rely on population models as a tool for integrating information, and the basic problem of integrating collision risk with population growth has already been addressed.

Many different modeling approaches exist in the scientific literature, and there are numerous guides and model selection criteria. The life cycle of each species presents a unique set of parameters called "*vital rates*" that must be addressed. In general a population can be defined as:

Equation 2. General structure of a matrix population model

$$P = \begin{bmatrix} 0 & F_1 & F_2 & F_3 \\ S_0 & 0 & 0 & 0 \\ 0 & S_1 & 0 & 0 \\ 0 & 0 & S_2 & S_{3+} \end{bmatrix}$$

Where the population ***P*** is a function of the fecundity ***F*** of each reproducing lift stage and their survival ***S*** through time, and similarly:

Equation 3. General structure of a differential population growth model

$$\mathbf{n}(t+1) = \mathbf{Pn}(t)$$

Where ***n(t)*** is a vector of stage abundances, ***P*** is the matrix defined in Equation 2, and ***n(t + 1)*** is the abundance at the next time step.

Models may be age structured (Leslie, 1945) such that organisms transition between stages with regular frequency (i.e. annually), or stage based (Lefkovitch, 1965) such that organisms can remain in stages for a variable period of time (i.e. until maturation). Each model, and the corresponding vital rates, can be disaggregated in space, between stages, or between populations or meta-populations (Caswell, 2001). Thus, in theory a solution to the realized impacts of wind energy facilities can be analyzed for any species or population. At any scale the appropriate collision probability can be applied to a stage or to the population as a whole to estimate the change in abundance or growth. However, these simple population models assume linear or exponential growth, and make no assumptions about density-dependance.

Hunt (2003) developed a modified Lefkovitch matrix for golden eagles based on Moffat's Equilibrium (Moffat, 1903). This design choice was biologically based. Like those of some other raptors (Hunt, 1998), golden eagle populations include sexually mature non-breeding adults that do not defend territories or nesting locations until they are made available via direct competition (i.e. fighting for a nest location), or because the occupying pair experiences mortality or selects a different location. Moffat's Equilibrium assumes capacity for territories, and allows for equilibrium between breeding birds and non-territorial "*floaters*" when territories are saturated. In the real world the occupation of territories and the role of floaters will be "*imperfect*". Other models may provide more utility when dealing with populations at very low abundances or addressing other species. However, golden eagle pairs and populations are reasonably approximated by these patterns, and are thus well suited to the Moffat model.

Hunt's golden eagle matrix includes survival rates for juvenile, subadult, adult, and birds older than 16 years. The matrix allows for density dependence in terms of a total number of breeding locations, and the maximum number of pairs that those locations provide. Fecundity is expressed as "*young per pair*" and is constant for all sexually reproducing birds. The matrix is a seeded discrete time series model, which includes a 25 year burn-in period followed by 100 years of growth. Randomness or variation can be included as a multiplier on survival for each year and life stage.

Performance metrics are expressed in terms of total population size, the abundance of breeding and non-territorial birds, and the average population growth rate Lambda. Although the model is not fully extensible to the long-term adaptive management requirements of the system (see below), it is well suited to the analysis of specific alternatives. In addition the model has been peer reviewed and applied to specific problems in the scientific literature. Therefor Hunt's golden eagle model was selected for the application of the analytical framework.

Resource Equivalency Analysis

Resource Equivalency Analysis (REA) is a method of environmental compensation analysis designed to produce cost estimates of environmental loss developed under the Natural Resource Damage Assessment Process (NRDA). REA, initially developed as Habitat Equivalency Analysis (HEA), evaluates loss in terms of some quantity in time, amortized against future estimates of loss and mitigation. REA has a long legal standing, and has been adopted by the USFWS in golden eagle permitting (USFWS, 2009b).

REA can be used to address either monetary valuations (i.e. the cost for killing a bird as a fee), or the cost of restoring lost ecological services (i.e. the requirements for mitigation). In the case of golden eagles, and for most wind energy impacts, the cost of restoration is the target because the service hopes to project a no-net-loss future for the managed species. The development of an REA includes the assessment of the appropriate service to measure and value, followed by a series of calculations and discounts for loss and mitigation.

The method was originally designed to address habitat loss in terms of acres and acre years. Habitat can be monetarily valued, purchased, and managed, allowing for a simple amortization of loss based on habitat quantity and time. In addition, since acres do not experience population dynamics, habitat can be valued equally in space and time. For example, the disturbance of ten acres for one year can be mitigated for by protecting one acre for ten years, and this is considered "*equivalent*" (hence the name of the methodology). REA treats animals similarly in the consideration of lost animal-years vs. credits towards gained animal years. Zafonte and Hampton (2005) provide an overview of the application to birds, and provide some guidance in addressing golden eagles.

REA seeks to compare services that are of "*the same type and quality, and of comparable value*", often termed *"in-kind*" restoration (NOAA, 1998 page 5). This is critical because the REA for golden eagles does not monetize the loss to the population from wind energy facilities, and is a key assumption in the no-net-loss calculations. The approach has some similarities to Patient-Template Analysis (Lichatowitch et al, 1995), and begins with an assessment of "*baseline conditions*" that would occur in the absence of the impact under consideration. Loss is considered in terms of the quantity of services lost (i.e. number of birds), adjusted for the number of years during which the service was lost.

Under their permitting program, USFWS has developed an application of REA specific to golden eagles and bald eagles, and has developed a spreadsheet application to facilitate analysis. In general, lost bird years are estimated as:

Equation 4. General formula for habitat or resource equivalency analysis

$$I = \sum_{t=0} (NB_t - N_t)/(1+r)^t$$

Where ***I*** is the injury in bird years, ***NBt*** is the number of birds at time t under a baseline scenario (i.e. no injury), ***Nt*** is the number of birds under the analyzed scenario (i.e. to be permitted), and ***r*** is an annual discount rate. Differences between ***NBt*** and ***Nt*** may be present due to direct mortality, or from any other changes in the vital rates between the two scenarios.

As Zafonte and Hampton point out, the loss in bird years is ultimately a question of population biology. Populations with slower growth rates will take longer recover from loss compared to those with faster growth. Thus "*the determination of the recovery path, or the duration of the injury, is central in determining natural resource damages using REA*" (Zafonte and Hampton, 2005 page 1019).

In practice REA assumes that loss occurs as an "*event*", and occurs in isolation. Loss is considered in terms of the recovery from one specific scenario which occurs at t=0, without reference to the underlying population dynamics. Zafonte and Hampton provide a clear path for incorporating population dynamics in the REA, and go as far as to present a life cycle model to that affect. In addition they demonstrate how environmental and population dynamics can influence the REA conclusions and may "*significantly underestimate temporal loss*" (Zafonte and Hampton, 2005 page 1020). They argue that "*The clear advantage of using population models is the ability to explicitly consider injured and baseline conditions…*" (Zafonte and Hampton, 2005 page 1022) when compared against the straightforward but less rigorous method of using estimates of individual birds in the REA.

Zafonte, Hampton and others have argued that the nonlinear and complex nature of population biology requires the use of a population model in REA in order to adequately estimate losses and predict recovery. Because most populations experience nonlinear dynamics, the importance of each bird is a function of the population context. At relatively low densities every breeding bird may influence the performance of a population. At higher densities floaters, immature birds, and even some breeding birds may be considered "*surplus*" (USFWS, 2009b), and may not be as valuable. In practice "*sustainable yield*" is a statistical concept that requires population modeling, and carries with it elements of uncertainty as do all of the aspects of REA/HEA (Hansen et al, 2013).

In our preliminary application of the framework presented below we ignore these aspects of population biology, density dependence, and sustainable yield in the REA analysis. However, we provide recommendations for improving REA by addressing these substantial concerns. Ultimately we believe that population management is compatible with the regulatory requirements of the MBTA and ESA, and we believe that REA-based impact assessments can be improved to incorporate the population viability metrics developed by Boyce, 1992 and elevated by McGowen and Ryan (2009). This will require further work by the regulatory agencies and others as described below.

Performance Criteria

"essentially, all models are wrong, but some are useful"[3]

George E.P. Box – October 18, 1919 – March 28, 2013

The analytical framework was developed to present a pathway for the evaluation of wind energy-wildlife interactions at various scales. The system is exploratory by design, and was developed to help describe natural phenomena; not to predict future outcomes at specific turbines. Such real world natural phenomena are too variable and complex to be accurately forecasted at such fine scales with any level of believability. As the recently-late statistician George E.P. Box once wrote, "*A man in daily muddy contact with field experiments could not be expected to have much faith in any direct assumption of independently distributed normal errors*" (Box, 1976, page 795).

The project objective was to provide an implementation of the framework as a proof of concept, along with documentation of the underlying model assumptions. This report and the corresponding citations provide a road map to each of the components of the framework. The bibliography contains the body of literature examined in the development of the framework. The performance of the corresponding data model, population model, and REA were initially evaluated in terms of their successful deployment in a computing environment before further testing.

Since the framework itself is not predictive, it was not developed to attain a specific level of statistical power, precision, or reliability. Therefore, we do not provide specific bench tests or performance criteria that might be used to evaluate specific scenarios or conditions. Instead the data model, collision estimates, population model, and REA are all deterministic within the stated level of variance presented for each variable, as are the subsequent distributions. The distribution across all random variables were generated via Microsoft® Excel® 2010 Version 14.0.7106.5003 (64-bit) using the Random function which is subject to its own performance testing. We evaluated the components of the framework in terms of the means and distributions of modeled variables.

The overall performance criteria for the analytical framework will be its influence on the adaptive cycle in the APWRA and elsewhere (Holling et al, 1995). In these adaptive management terms the framework aims to support the re-organization/renewal phase of wind energy development. Re-organization/renewal is one of four steps in the evolution of adaptive management systems that allows for improved efficiencies and expanded consumption without sacrificing the environmental footprint (Holling et al,1995). In many cases this phase is preceded by release of the resource, followed by growth of the consumptive system, and the APWRA appears to be no exception.

Initial development in the APWRA and elsewhere occurred during the 1980's and 1990's initiating the adaptive cycle. Settlement agreements, interim permits, and un-permitted take allowed for ongoing operation of wind energy facilities, despite mounting evidence of avian wildlife impacts. In the APWRA this was followed by various conservation measures such as hazardous turbine removal, and subsequent "*resource release*" (Holling et al, 1995) by regulatory agencies in the form of plans for repowering.

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[3] Taken from Box, G.E.P. and Draper, N.R. (1987). Empirical Model-Building and Response Surfaces, Wiley & Sons, N.Y. page 424.

The fundamental performance metric for the analytical framework is its utility and use in the adaptive management process, and its capacity to explain and address the fundamental issues raised by the resource conflict. The fundamental issues presented to the framework were raised during early reporting and peer review in the APWRA (ICF International, 2011) and elsewhere. Namely:

1) Absence of a scalable data management system
2) Lack of transparency in the estimation of collision risk
3) Confusion in the linkages between individual fatalities and outcomes at larger scales

During the past several years the APWRA bird fatality study has developed and described the data management system, and provided transparency in the estimation of collision risk (ICF International 2010, 2011, and 2012)[4]. The model description and assumptions presented above provide specific references to those accomplishments.

The outstanding performance criteria for the analytical framework as a whole is to further the adaptive management process by providing a scalable system which can be used to define linkages between individual fatalities and outcomes at larger scales. Therefore, we evaluated the framework in terms of its ability to describe environmental impacts at multiple scales to describe linkages between individual fatalities and population level outcomes. Finally, we evaluated the framework in terms of its ability to provide linkages to an REA-based impact assessment.

Test Results

The conceptual model was disaggregated into ten discrete sub-networks (Appendix A) based on within-network connectance. The sub-networks, called "*Conceptual Model Diagrams*", are ordered within their domains, but unordered with respect to each other. Each of the ten diagrams is required to produce the deterministic solution to the framework, though individual elements of the sub-networks may be non-orthogonal or redundant. The conceptual model information is partial at best, and the corresponding diagrams should be considered straw-man. However, the sub-networks provide a reasonable and transparent framework for organizing information across domains and managing concept experts.

The data model SQL create statements were successfully tested and deployed in a Microsoft® SQL Server® 2008 instance. ICF International hosts a forward facing version of the data model at ecosystems.icfi.com. Create statements from Appendix C can be used to test the data model deployment in Microsoft® SQL Server®. Deployment to other relational database platforms was not tested, but in theory the Microsoft® T-SQL statements should be translatable to other environments.

The population model and REA spreadsheet model were previously tested and published by their corresponding authors. The modified models (see below) were tested and deployed in a Microsoft® Windows® 7 Enterprise Version 6.1 Build 7601: Service Pack 1 64-bit environment using an Intel® Core™ i7 2.67 GHz CPU with 7.86 GB RAM. No computational resource conflicts or stability issues were identified or experienced.

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[4] Other studies have furthered this area of science as well and were referenced above.

Based on the conceptual, data, and collision risk models the three-year APWRA baseline golden eagle annual fatality estimate was 55 birds per year, with a 95% confidence interval just slightly larger than the 3-year 5% standard error of 52-58 birds (ICF International, 2013). The most recent estimates, following management actions including turbine removal, were closer to 40 individuals per year. However, the baseline fatality rate in the APWRA was used for demonstration purposes to provide an estimate of the potential long-term unregulated project impacts. The year-to-year range of APWRA-wide golden eagle fatality estimates was 38 to 68 individuals, or 0.69 to 1.24 times the 3-year geometric mean of the point estimate. The 10 year point estimate for APWRA-wide golden eagle fatalities was 1,100 individuals, or approximately 2,200 kg (2.2 metric tons) of golden eagle based on an average of 4 kg per bird (Carey, 2003).

From a population perspective the source of golden eagle fatalities remains uncertain. Initial studies suggested that a large portion of these birds are from a local breeding population (Hunt, 2002), but that assumption has not been rigorously tested. Regional estimates of golden eagle abundance suggest that the Bird Conservation Unit in which the APWRA resides supports approximately 800 breeding birds or 400 pairs (Good et al, 2004 & 2007).

We tested the population-level influence of APWRA-wide golden eagle fatalities on various sizes of breeding populations ranging from the Bird Conservation Region (~800 breeding birds) to the local level (~100 breeders) based on 10,000 simulations (1,000 per scenario) of Hunt's (2003) golden eagle model (Table 2). Average changes in survival were distributed evenly across life stages, and were permutated by a 10% random variation in annual survival at each stage. We examined the relationship between population size and population performance based on simple 2nd order polynomial regression.

Table 2. Average configuration parameters for 10,000 simulations of Hunt's (2003) golden eagle population model at various population sizes.

Breeders At Saturation	Approximate Baseline Population Size (Breeders Plus Floaters)	Pairs at Saturation	Average Baseline Impact on Annual Survival
100	190	50	34%
200	380	100	17%
400	775	200	8%
600	1150	300	6%
800	1525	400	4%

APWRA-wide fatalities had a substantial influence on floater abundance and variability at all scales, with an increasing impact at smaller population sizes (Appendix D., Figures 1-5). At the local level Baseline APWRA-wide fatality rates may be substantially limiting or even eliminating non-territorial Floaters (Appendix D., Figure 2). Assuming population Lambda, Moffet's Equllibrium, Breeders, Juveniles, and Subadults appear to be unaffected by APWRA golden eagle fatalities at all scales examined.

We tested the influence of annual variability in APWRA-wide golden eagle fatalities in a population of 800 breeding birds as an analogue for the Bird Conservation Region. We generated an additional 14,000 simulations by increasing annual random variability in the survival schedule for each stage, moving in 5% increments from 10% to 40% of the point estimate of survival for each stage. We examined the relationship between variance in survival and each performance metric using simple 2nd order polynomial regression.

Increased variability in APWRA-wide fatalities resulted in decreased population Lambda and the abundance of Breeders, Floaters, Subadults, Juveniles, and Adults, and resulted in increased standard deviation in abundance for each stage (Appendix D., Figures 6-10). Although there were differences between Baseline and Mitigated conditions, these differences were not significant based on the 95% confidence area for the two curves (Appendix D., Figures 6-10). Most simulations had an average population Lambda of <1 for survival rates that had a 20% coefficient of variation in annual survival or greater (Appendix D., Figure 6).

Based on the USFWS calculations (2009b) and the APWRA life history assumptions described by Hunt (2003), the unmitigated loss of 55 golden eagles from a population of 400 breeding pairs is 332.13 bird years in the first year of operations. The 10 year total loss without reference to lost reproduction (i.e. the direct debt) is 2,981.12 bird years (Table 3). The density independent 10 year loss of all potential production from all fatalities at a rate of 55 individuals per year is more than 91 million bird years. This is undoubtedly a radical over estimate of loss because it ignores Moffat's equilibrium and meta-population structure of the Bird Conservation Region (see below), but it provides the reader with some insight into the mathematical magnitude of the loss calculations.

Table 3. Theoretical direct loss by year based on Baseline unmitigated APWRA-wide fatalities.

Year	Bird-Years
2012	332.13
2013	322.46
2014	313.07
2015	303.95
2016	295.09
2017	286.50
2018	278.15
2019	270.05
2020	262.18
2021	254.54
Total Bird-Years	**2918.12**

Project Goals and Accomplishments

Our objective was to develop a scalable analytical framework for standardized assessment of long-term impacts of wind turbine operations on avian and chiropteran wildlife. The framework was developed to generate estimates of the cumulative impacts of turbine strikes and habitat changes on long-term population performance in the context of a species demography, genetic potential, and life history. This work will reduce applicant risk and the burden on regulatory agencies by providing both parties with a standardized analytical framework for data management and impact analysis.

This project identified an analytical framework for assessment of wind power project impacts on birds and bats. The deliverables consist of an explicit conceptual foundation describing the scientific logic applied to the problem, and a set of software tools based on that logic. The software tools include a Microsoft® Silverlight® based conceptual model, a Microsoft® SQL Server® managed data model, a Microsoft® Excel® based population model, and a Microsoft® Excel based Resource Equivalency Analysis. The purpose of this work was to facilitate assessment and permitting of wind power projects.

We completed a literature review, and a conceptual model describing the analytical framework. We participated in technical and policy meetings, and facilitated expert panel and stakeholder review through direct and interagency meetings. We identified concept experts using the bibliography, and extracted draft framework assumptions using existing literature. We described the underlying assumptions of the analytical framework, developed draft model inputs, and performed a permutation analysis of the draft framework components. The project provided an examination of the draft framework behavior, and documentation for reproducing the analysis. Finally, ICF administered and managed the project from inception to closure.

Conclusions

ICF provided a template for environmental impact assessment of wind energy facilities. This framework will allow applicants to make their assumptions more transparent in regards to the nature and extent of their impacts, and the potential for each species to respond to those changes. In addition it should allow the regulatory agencies to more explicitly examine cumulative impacts through extension of the tool set.

The underlying data model is resolvable and conformed to normalization. The information landscape and underlying management issue was found to be similar to the general problems addressed by the USFWS (2009a) Waterfowl Adaptive Harvest Management (AHM) program (e.g. Millsap and Allen, 2006). As with AHM, wind energy impact analysis seems well suited to an examination of density dependent and independent impacts.

APWRA-wide fatality rates appear substantial at all scales examined, and significantly influenced population performance in terms of Floater performance. Breeder, Juvenile, Subadult, and Adult abundance were mostly unaffected by Baseline APWRA-wide fatality rates. However, increased variability in fatality rates would likely have impacts on long-term population performance, and would result in a substantially larger REA estimate.

Project Problems and Unresolved Issues

The project experienced numerous problems in schedule, and significant shortfalls in available resources due to adaptive and technical barriers. Project initiation by DOE was late due to uncontrolled budgetary issues, resulting in an approximately one year delay of start-up. During this latent period alternative Project Director and technical staff were required, and additional training was needed. Key staff including the Principle Investigator experienced uncontrolled absences. These delays required accommodation on all parts, especially that of DOE.

ICF made a substantial cost match to the project budget, and contributed project resources beyond plan. These sacrifices in budget and scheduling greatly improved the quality of our analysis, and allowed the product to be relevant and comprehensive. Aside from these project management problems, some technical issues remain unresolved.

During the first and second phases of the project (literature review and development of the conceptual model) it became evident that the project could not fully address the level of grass roots collaboration that was desired and the level of analysis that was needed. Fortunately it also became apparent that most of the needed collaborations were already established in the non-profit, agency, academic, and private institutions participating in groups such as AWWI, NWCC, AWEA, and the APWRA. The collective knowledge of these institutions was deemed sufficient to define and describe an analytical framework to address the problem statement.

During the third stage (development of the framework) the project shifted away from interviews and knowledge building towards the review and consumption of the large body of published literature previously assembled by concept experts. This greatly decreased the opportunities for collaborative online conceptual model development and peer review. Therefore, the online conceptual model remains an impression sketched by ICF based on our understanding of the existing literature.

We believe the model to be reasonable, and the analytical framework itself has been extensively peer reviewed. However, the conceptual model requires a specific instance of documentation which is only as useful as the support of its community of experts. Without financial, social, or professional incentives it may not be practical to secure sufficient peer review of the conceptual model or participation in its improvement.

The emerging analytical framework was communicated to members of the aforementioned workgroup in direct interviews and in technical presentations to AWEA, NWCC, and the California-Nevada Golden Eagle workgroup (Schwartz and Clayton, 2009, Schwartz and Leslie, 2010, and Schwartz et al, 2012). Many of the conceptual relationships and analytical recommendations readily accepted. However, certain biological uncertainties remain unresolved in expert opinion and agency policy.

The scale of biological relevancy of the analysis has yet to be identified, making the impact assessments and mitigation prescriptions difficult to interpret in some cases (Schwartz et al, 2011). To be fully implemented the analytical framework must also be driven by one or multiple models of population performance for each managed species or species group (USFWS, 2009a). Despite his role as a highly respected concept expert, the work of Hunt has yet to be fully integrated into the regulatory framework.

The approach to REA prescribed by the USFWS has not been sufficiently reviewed by the scientific community. The general approach has been used extensively by the regulatory agencies (NOAA, 1995 and 1999) and has been applied to birds with some success (e.g. Zafonte and Hampton, 2005). However, the previous applications of REA which have withstood legal challenges were designed to address episodic issues such as oil spills or forest fire (e.g. Hansen et al, 2013). The impacts of wind energy on wildlife are ongoing and may have sustained impacts to their population biology.

Population viability analysis may be a useful contribution to the assessment, but cannot be used to support REA if extirpation is not the concern (Boyce, 1992, McGowan and Ryan, 2009, and Morris and Doak, 2002). The real-world impacts of wind energy to golden eagles or other wildlife most likely lie between the end points of individual fatalities and population extinction, and the assessment of their equivalency requires the selection of an appropriate and sensitive performance metric (Kohler and Dodge, 2006). The use of population performance metrics demonstrated in this report provides a starting point for consideration in the scientific and regulatory communities. However, we were unable to thoroughly examine these issues during the project period.

Metrics such as population capacity, productivity, recruitment, and/or resiliency may more useful than the analysis of individual birds. In comparison to the examination of individual fatalities, the REA of population performance metrics under Moffat's Equilibrium will undoubtedly reduce the apparent value of wind-turbine related fatalities. However, the use of population models will also discount the expected value of mitigation relative to the estimated benefits to the population under equilibrium. This will require mitigation planners to develop actions that address real-world bottlenecks in the population, and to move beyond simple accounting and amortization. We were unable to develop and implement a permutation analysis of the REA, and were therefore unable to suggest a reasonable alternative to the existing approach. This key uncertainty remains for future consideration, and will require the attention of experts and stakeholders.

We were unable to thoroughly examine the influence of background mortality. Electrocution appears to be a widespread source of mortality for Golden Eagles in North America (Benson 1981, Harness and Wilson 2001). In a now dated study over 300 electrocutions of Golden and Bald eagles were documented in the United States during a 3-yr period (Boeker and Nickerson 1975). During a different 2-yr period, an additional 250 Golden Eagles were found electrocuted in 14 states, mostly in Utah (32%), Nevada (24%), Idaho (12%), and Montana (10%) (Boeker and Nickerson 1975). Many electrocutions occurred along a few stretches of power line; for example, 37 electrocuted Golden Eagles were found along 24 km of power line in Colorado, and 47 electrocuted Golden Eagles were found along 19 km in Utah. Sixteen (94%) eagles killed by electrocution in the Pawnee National Grassland in Colorado were immature. These electrocutions underscore the USFWS reasoning for examining electrical facility retrofits for mitigation, however numerous other sources of background mortality exist. Of 26 known mortalities in a radio-tracked population of Golden Eagles during the mid-1990's in California, 19% died from electrocution (Hunt et al. 1997), but the remaining individuals died from other sources that will also limit population performance. Each of these may represent an important target for mitigation as well (e.g. Friend et al, 2009).

Finally, we were unable to examine extinction risk within the draft analytical framework. The approach to Population Viability Analysis (PVA) has been extensively describe (e.g. (Morris and Doak 2002). PVA is a central component to the development of a Biological Opinion by the regulatory agencies (e.g. (USFWS 2008), and would allow the agencies to evaluate the contribution to jeopardy for various management alternatives.

Further Research

Based on our experience in the project we offer the following recommendations for future research:

Recommendation 1: *Establish concept experts through the existing system of non-profits, regulatory agencies, academia, and industry*. The conceptual model exists, but the level of review and contribution by experts is far below that which was anticipated by this project. Aside from the recommendations implied by our review of the existing community, concept experts must be selected by the appropriate venue (see Recommendation 3). Incentives must be established to secure participation by experts before large improvements to the conceptual model can be expected.

Recommendation 2: *Develop a central or distributed shared data repository, and establish guidelines for transparency*. Wind carries energy and birds, and moves from the shared commons to the private sector on its way from the high seas, to proprietary airspace, to private and public transmission systems. Although some of the data concerning wind energy and wildlife is clearly proprietary (i.e. operational capacity, on-site wind conditions, and financial information), other data address issues that are important to all of the stakeholders involved and do not threaten the financial performance of individual projects or developers. These include the location, turbine height, and rotor swept area of all turbines to which a particular species is exposed, and perhaps even the post-construction bird use and actual fatalities of each facility. The appropriate metrics and scales of aggregation must be considered carefully by all parties involved, but the value of a shared system to assess cumulative impacts at the national level is not in question in the scientific literature.

Recommendation 3: *Develop a forum and process for model selection*. The Adaptive Harvest Management (AHM) program implemented by the USFWS provides a well-tested example of a collaborative model selection process for integrating population biology and ecology with regulation of issues governed by the MBTA. While this program is not “plug-and-play” with wind energy issues, it does set precedent for the extension of the model selection process to other MBTA issues or those addressed by BGEPA. Most notably, the AHM has been shown to be effective in bringing together concepts of population productivity, habitat capacity, direct take, and mitigation using multiple models. A related program, established collaboration between the regulatory agencies, existing non-profits, experts, and stakeholders, would provide a venue for the examination of existing models and selection of the most useful systems for each species or bird group under consideration. Such a program would fit well with the mission of existing collaborations such as AWWI, NWCC, or, at a smaller scale, the CA-NV Golden Eagle Working Group.

Recommendation 4: *Implement the prescribed system at broader scales, and refine the expectations for adaptive management*. The establishment of concept experts, construction of a shared data repository, and development of a model selection forum will greatly improve the quantity and quality of collaboration surrounding wind-wildlife issues. This work will allow participants to move beyond the much needed conversations and recommendations of existing processes, and into the realm of establishing shared systems (William and Smith, 2003). Once implemented at broader scales cumulative impacts will likely be more apparent as will potential limitations on population performance and potential targets for REA analysis and mitigation. We recommend that agencies use this phase as an opportunity to re-examine the level of biological monitoring, and the quality of available information. Procedures for revising the adaptive management prescribed by USFWS are readily available to the problem. We recommend that these practices be implemented iteratively for the life of the management issue (e.g. Gunderson, 1995 and USFWS, 2009a).

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