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A REVIEW OF OPTIONS FOR MITIGATING TAKE OF GOLDEN EAGLES AT WIND ENERGY FACILITIES

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Abstract.—Wind energy development has expanded rapidly in the past decade, becoming a significant source of electricity, and a major element in a global strategy to reduce carbon emissions and the effects of climate change. Golden Eagles (*Aquila chrysaetos*) can collide with wind turbines, adding to the existing and substantial mortality from other anthropogenic sources. These collisions are a conservation concern, and they pose a legal risk to wind energy companies and potentially hamper development in areas where the range of Golden Eagle overlaps areas of high wind energy potential. The U.S. Fish and Wildlife Service, through the revised Eagle Rule and the Eagle Conservation Plan Guidance, has designed a mitigation strategy for eagle conservation that allows wind energy companies to obtain incidental take permits. However, the strategy is challenged by a lack of data supporting scientifically rigorous strategies to mitigate eagle take, where mitigation is defined as efforts to avoid and minimize take, and compensate for unavoidable take. We review the steps and options a wind developer can consider to mitigate predicted eagle collisions with wind turbines consistent with the U.S. Fish and Wildlife Service's revised Eagle Rule and Eagle Conservation Plan Guidance. Most of these options have limited or no scientific support and their effect on reducing risk of eagle collisions is unknown. We briefly describe approaches for evaluating technology intended to minimize eagle take and for developing options to offset unavoidable eagle take that are quantifiable and verifiable. Because estimates of Golden Eagle fatalities at many wind energy projects are low, research to evaluate mitigation measures needs to be coordinated and collaborative across multiple wind energy facilities to improve our ability to produce scientifically robust mitigation strategies. The impetus for these efforts is improving implementation and compliance with the revised Eagle Rule, but the results have benefits beyond Golden Eagles, for raptors and their ecological communities.

Key Words: *Golden Eagle*; Aquila chrysaetos; *mitigation*; *mortality*; *take*; *wind energy*.

REVISIÓN DE LAS OPCIONES PARA MITIGAR LA DESAPARICIÓN DE *AQUILA CHRYSAETOS* EN INSTALACIONES DE ENERGÍA EÓLICA

Resumen.—El desarrollo de la energía eólica se ha expandido rápidamente en la pasada década, convirtiéndose en una importante fuente de electricidad y un elemento clave en la estrategia global para reducir las emisiones de carbono y los efectos del cambio climático. Los individuos de *Aquila chrysaetos* pueden colisionar con los aerogeneradores, lo que se suma a la mortalidad sustancial existente ocasionada por otras actividades antrópicas. Estas colisiones constituyen una preocupación para la conservación de la especie, plantean un riesgo legal para las compañías de energía eólica y potencialmente obstaculizan el desarrollo en áreas donde la distribución de *A. chrysaetos* se superpone con áreas de alto potencial de energía eólica. El Servicio de Pesca y Vida Silvestre de los Estados Unidos, a través de las nuevas versiones de la Regla

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Águila y de las Directrices del Plan de Conservación de Águilas, ha diseñado una estrategia de mitigación para la conservación de las águilas que le permite a las compañías eólicas obtener permisos de desaparición accidental. Sin embargo, la estrategia se ve dificultada por la falta de datos que apoyen científicamente estrategias rigurosas para mitigar las desapariciones de águilas, en las que la mitigación es definida como esfuerzos para evitar y minimizar las desapariciones y compensar aquellas que sean inevitables. Revisamos los pasos y las opciones que las compañías de energía eólica pueden considerar para mitigar las colisiones esperadas de águilas con aerogeneradores, consistentes con las nuevas versiones de la Regla Águila y de las Directrices del Plan de Conservación de Águilas del Servicio de Pesca y Vida Silvestre de los Estados Unidos. La mayoría de estas opciones tienen poco o ningún apoyo científico y su efecto sobre la reducción de las colisiones de águilas es desconocido. Describimos brevemente enfoques cuantificables y verificables que pueden usarse para evaluar la tecnología utilizada para minimizar las desapariciones de águilas y para desarrollar opciones que compensen las desapariciones inevitables. Debido a que las estimaciones de mortalidad de *A. chrysaetos* son bajas en numerosos proyectos de energía eólica, las investigaciones para evaluar las medidas de mitigación deben ser coordinadas y colaborativas considerando múltiples instalaciones de energía eólica, para incrementar nuestra capacidad de producir estrategias de mitigación científicamente sólidas. El estímulo para estos esfuerzos es aumentar la implementación y el cumplimiento de la nueva versión de la Regla Águila, pero los resultados tienen beneficios más allá de *A. chrysaetos*, para las rapaces y sus comunidades ecológicas.

[Traducción del equipo editorial]

Wind energy has been one of the fastest growing sources of electricity in the U.S. (and the world), growing from less than five gigawatts in 2002 in the U.S. to more than 82 gigawatts by the end of 2016 (American Wind Energy Association [AWEA]), and it is considered to be a major component of a global strategy to reduce carbon emissions and the effects of climate change on wildlife. There are multiple factors influencing the future pace and scale of this energy source: (1) reduced greenhouse gas emissions goals—analyses of carbon budgets assume that substantial growth in wind energy in the U.S. would be needed to achieve the reductions in carbon emissions necessary to limit the potentially catastrophic effects of climate change (approximately 82 gigawatts installed currently to 330–440 gigawatts installed by 2050; Mai et al. 2012, Clemmer et al. 2013); (2) state renewable electricity, or portfolio, standards—twenty-nine states and the District of Columbia have legislated goals to increase electricity production from renewable energy; seventeen states have set goals of 20% or higher. Meeting those standards is estimated to require 87 GW of new development (Union of Concerned Scientists 2013); (3) cost—the average cost of wind energy that includes capital, construction, fuel, and operating costs, is similar to or less expensive than most other sources of electricity (approximately $50–63/MWh; United States Energy Information Agency [USEIA] 2016, Wiser and Bollinger 2015); and (4) relative environmental impacts—wind energy consumes no water in the production of electricity, unlike thermally generated electricity (Averyt et al. 2011), and its cumulative environmental impact may be lower than that of other sources of electricity (Newman and Zillioux 2009, Sovacool 2013).

Golden Eagles (*Aquila chrysaetos*) can collide with turbines, adding to the substantial mortality from other anthropogenic sources, including shooting, electrocution, poisoning, and vehicle strikes (U.S.F.W.S. 2016a). Golden Eagles are protected under the Bald and Golden Eagle Protection Act (BGEPA), and collisions at wind turbines pose a legal risk to wind energy companies, potentially affecting development in regions of the U.S. where the range of Golden Eagles overlaps areas of high wind energy potential. The BGEPA allows for the take of Golden Eagles if such take is compatible with the preservation of the Golden Eagle (U.S.F.W.S. 2016b), The U.S. Fish and Wildlife Service (hereafter, Service) refers to this compatibility as the "preservation standard," and they define this standard as "consistent with the goals of maintaining stable or increasing breeding populations in all eagle management units and the persistence of local populations throughout the geographic range of each species" (U.S.F.W.S. 2016b).

The Service, through its 2009 Eagle Rule and 2016 revision (hereafter, Rule) and the Eagle Conservation Plan Guidance (hereafter, Guidance; U.S.F.W.S. 2013), has designed an approach that enables wind energy companies to obtain a permit and incidentally take Golden Eagles during the operation of a wind energy facility (U.S.F.W.S.

2016b). Because of the concerns about population trends (Katzner et al. 2012a, Millsap et al. 2013, U.S.F.W.S. 2016a), the Service has concluded that Golden Eagle cannot sustain additional mortality, and thus has established a policy of "net benefit, or at minimum, no net loss" for this species; any permitted take must at least be quantifiably and verifiably offset by actions taken by the permit holder that either reduce Golden Eagle mortality from another source or increase Golden Eagle productivity (U.S.F.W.S. 2013). As described in the recently revised Rule, the Service can issue Eagle Incidental Take Permits up to 30 yr in length, including reviews of compliance with permit conditions every 5 yr (U.S.F.W.S. 2016b).

Since the release of the original 2009 Rule, three 5-yr take permits have been issued for take of Golden Eagles at wind energy facilities (Shiloh IV, Solano County, CA, Alta East, Kern County, CA, and Choke Cherry Sierra Madre, Phase I, Carbon County, WY). A small number of environmental assessments of eagle permit applications, including eagle conservation plans, have been released and undergone public review, although according to the Service, numerous permit applications are in the queue.

Implementing and complying with the Rule is challenging because of the lack of approved options to minimize take, as well as the limited approved options to compensate for take, which include only the retrofitting of power poles (U.S.F.W.S. 2013). We here review several proposed options to mitigate the effects of the development and operation of wind energy facilities on Golden Eagles, where mitigation is defined as efforts to avoid and minimize adverse effects on Golden Eagles, and to compensate for unavoidable adverse effects after avoidance and minimization measures have been taken (U.S.F.W.S. 2012).

Options to Mitigate Eagle Take at Wind Energy Facilities

The organization of our review follows the framework used by the Service in the Guidance (U.S.F.W.S. 2013) that describes how wind project developers might: (1) predict and avoid eagle take; (2) minimize predicted take; and (3) compensate or offset any remaining take to achieve "no net loss" to the regional and local Golden Eagle population. For each method, we briefly describe the approach and its purpose, any existing or proposed implementation, and any information on effectiveness. A list and a brief description of all potential actions can be found in Table 1.

Predict and Avoid Take. As a first step, a project developer must predict eagle take using the Service's Bayesian take prediction model (New et al. 2015). The result of this step can form the basis of a decision to build or not build a project or to alter its size and configuration, thereby reducing the take prediction. The prediction is used to define the site risk category: Category 1 sites are near high eagle-use areas or where predicted take exceeds 5% of the local population; Category 2 sites are lower risk, where predicted take is between >0.03 eagles per year and 5% of the local population, but predicted take can be minimized and offset; and Category 3 sites are considered the lowest risk, with predicted take of <0.03 eagles per year. Most projects are expected to have a lifespan of 30 yr, and any project with a take prediction of one or more eagles over the lifespan of the project will be classified as a Category 2 site and its developers encouraged to seek a take permit. The Service has recommended that Category 1 sites be avoided or project plans be modified to lower take predictions, thus converting these sites into Category 2 sites. In contrast, Category 3 sites would not need a take permit (U.S.F.W.S. 2013).

The Service Bayesian model incorporates a prior exposure rate that is updated with the results of preconstruction activity surveys; exposure is estimated using the number of minutes that eagles are observed within 800 m of point count locations and at a height up to 200 m. The activity results are multiplied by an expansion factor that estimates the proposed project's hazardous footprint, which includes the number of turbines in the project. This product is then multiplied by a "collision probability prior," defined as "the probability of a bird death per minute of pre-construction exposure" (New et al. 2015). This prior was calculated by the Service based on Golden Eagle activity and fatality data collected at four wind facilities in the U.S. (New et al. 2015).

Other than abandoning the proposed project, the simplest option for avoidance leading to a reduction in predicted take is to reduce the number of turbines for a proposed project. Such a reduction could convert a Category 1 site to a Category 2 site, or a Category 2 site into a Category 3 site. For example, a proposed 100-turbine project would need to record only 1 min of eagle activity in 490 hr of surveys to have a take prediction of approximately one eagle in 30 yr, resulting in a recommendation to seek a take permit (Bay et al. 2016, K. Bay

Table 1. A summary and brief description of options to avoid, minimize, and compensate for take of Golden Eagles as discussed in the text. Listed references describe use of the options at operating facilities or provide more theoretical support for the application of the option.

STRATEGY	OPTION	DESCRIPTION	REFERENCES
Avoid	Macro-siting	Avoid siting projects in high-use areas and high-risk topography	Smallwood et al. 2009, Katzner et al. 2012b, Miller et al. 2014
Avoid	Reduce turbine number	Eliminate turbines from high-risk areas and/or reduce exposure	Bay et al. 2016, ICF International 2016
Minimize	Attractant removal	Remove carrion, perches, and attractions for eagle prey	United States vs. Duke Energy Renewables 2013
Minimize	Flight diverters	Install pylons to divert birds around projects or guyed MET towers	U.S.F.W.S. 2013
Minimize	Nest management	Inhibit nest-building; remove or modify nest sites	U.S.F.W.S. 2016b
Minimize	Curtailment	Shutdown high-risk turbines or when eagles are at risk of take	De Lucas et al. 2012, Tetra Tech 2012
Minimize	Turbine micro-siting	Use turbine setbacks or avoid high-risk areas	Young et al. 2003, Smallwood et al. 2009, Katzner et al. 2012b, Miller et al. 2014
Minimize	Deterrence	Employ systems that detect and emit acoustic signals intended to alter flight path	May et al. 2012
Compensate	Power pole retrofitting	Replace "problem" poles with APLIC-recommended equipment	U.S.F.W.S. 2013
Compensate	Voluntary lead abatement	Subsidize use of non-lead ammunition or removal of gut piles	Cochrane et al. 2015
Compensate	Roadkill removal	Remove roadkill to reduce vehicle strikes	Tetra Tech 2012
Compensate	Prey habitat improvement	Improve prey habitat to increase eagle productivity	Steenhof et al. 1997
Compensate	Nest-site enhancement	Provide protection or shading for nests	Kochert et al. 2002
Compensate	Rehabilitation	Rehabilitate non-collision injured eagles	Wiemeyer 1981, Martell et al. 1991

pers. comm.). That same level of activity recorded for a 50-turbine project would reduce the take prediction below the threshold recommended for a take permit; the permit threshold for a 50-turbine Category 2 site would require a higher level of eagle activity—1 min of eagle activity recorded in 250 hr of surveys. Reducing the number of turbines could, of course, negatively affect the economic viability of the project.

Although activity has been shown to be a good predictor of collision risk for Golden Eagle (ICF International 2016), other factors such as eagle avoidance behavior, whether the observed eagles are breeding, wintering, or migrating, and site topography as it relates to eagle use also may influence collision risk at a proposed project (Smallwood et al. 2009, Katzner et al. 2012b, Johnston et al. 2014, Miller et al. 2014). It is not known how these factors quantitatively affect collision risk, and the Service Bayesian take prediction model does not directly consider these factors in predicting take.

The collision probability prior, by incorporating data on activity and eagle fatalities from existing projects, implicitly integrates the influence of these factors on collision risk (New et al. 2015). However, the collision prior is based on a small number of projects, three of which were older-generation turbines, and the relationship between activity and collision probability at older projects may not represent the collision risk at projects with modern turbines. "Repowering," or the replacement of older-generation turbines with taller, more powerful turbines, at the Altamont Pass Wind Resource Area (Altamont) appears to be reducing collision fatalities of Golden Eagles and other raptors (Smallwood and Karas 2009, ICF International 2016).

The Bayesian structure of the take model facilitates incorporation of new data, and the Service assumes that post-construction activity and fatality data at a permitted site can be used to update the collision prior and revise the take prediction for that site (U.S.F.W.S. 2013). Data from additional projects presumably could provide a more accurate and representative collision prior (Bay et al. 2016). However, in the absence of additional data, eagle take may be overestimated, and, therefore, the mitigation effort conditional on the permit would likely be overestimated as well. During permit review or renewal, if post-construction fatality surveys indicate an over-prediction of eagle take, the project operator may credit mitigation based on the over-predicted take to the permit renewal or the next 5-yr permit review period (U.S.F.W.S. 2016b).

Minimize Predicted Take. After predicting take, the 2013 Guidance indicates that project developers should apply measures that further avoid and minimize predicted eagle fatalities. In the 2009 Rule and 2013 Guidance, these measures were referred to as Advanced Conservation Practices. The revised 2016 Rule eliminates this phrase and the corresponding requirements; the Service now requires "potential permittees to implement all practicable best management practices and other measures that are reasonably likely to reduce eagle take" (U.S.F.W.S. 2016b). These measures remain to be identified specifically; but, as we discuss below, there are measures that are regularly being applied at permitted projects or proposed for projects seeking permits. Identification of additional measures for use at a specific project can be based on an assessment of the fatality risk factors determined for that project location or projects at similar locations.

In the context of developing an Eagle Conservation Plan, it is not sufficient to identify a measure intended to reduce eagle take; the measure needs to quantifiably reduce predicted take, consistent with the steps outlined in the Rule and the Guidance. For example, a draft Eagle Conservation Plan must describe the take prediction resulting from eagle activity surveys, and then describe how the minimization measures reduce predicted take from, for example, four eagles per year to a predicted take of two eagles per year. Quantifying the effects of minimization measures is a necessary step because any remaining predicted take must, in turn, be quantifiably offset by compensatory mitigation. To our knowledge, the effect of these measures on reducing collision risk for eagles is unknown. Other than reducing numbers of turbines or moving turbines to avoid disturbance to eagle nests (U.S.F.W.S. 2016c), no mitigation credit, (i.e., reduction in the take prediction) has been granted to projects employing other measures.

Best Management Practices (BMPs). The following activities intended to reduce take of Golden Eagles have been (1) proposed for projects that have been issued take permits; (2) recommended in Draft Environmental Assessments (DEA) and Eagle Conservation Plans for projects seeking eagle programmatic take permits (U.S.F.W.S. 2011, Tetra Tech 2012, ICF International 2014, U.S.F.W.S. 2014, U.S.F.W.S. 2016d); or (3) included in the Compliance Plans that were part of the Duke Energy and PacifiCorp plea agreements (United States of America vs. Duke Energy Renewables, Inc. 2013, United States of America vs. PacifiCorp Energy 2014; Table 1). These practices include implementing Avian Power Line Interaction Committee (APLIC)-approved recommendations to reduce the risk of eagle electrocutions, such as burying transmission lines and using APLIC-approved power poles to avoid electrocutions (APLIC 2006). These BMPs also include using meteorological towers that are not guyed and restricting driving speed by workers to reduce vehicle collision risk.

Other specific actions to minimize take described below are also intended to reduce eagle activity within the project footprint. As enforced by the Service, the definition of take includes "disturb," which the Service further defines as "to agitate or bother a Bald or Golden eagle to a degree that causes, or is likely to cause, based on the best scientific information available (1) injury to an eagle, (2) a decrease in its productivity, by substantially interfering with normal breeding, feeding, or sheltering behavior, or (3) nest abandonment, by substantially interfering with normal breeding, feeding, or sheltering behavior (U.S.F.W.S. 2016e). It is unclear when or whether proposed actions to reduce eagle activity within a project footprint could create sufficient disturbance so as to constitute "take" under this definition.

Attractant removal. The goal of this measure is to reduce eagle activity within the project area and potentially shift that activity to areas outside the project footprint either by reducing eagle perches within the project area to reduce activity and presumably reduce collision risk, or by reducing food resources within the footprint of the wind energy facility. The latter includes removal of carcasses of wildlife or livestock and identification of prey reservoirs, such as rock piles or other landscape features that might harbor eagle prey (U.S.F.W.S. 2013). This measure might also include augmenting food resources outside the project boundary to attract eagles away from the facility.

Flight diverters. The Service recommends the use bird flight diverters on guy wires (U.S.F.W.S. 2013). Some projects have begun installing pylons in select locations to determine whether the pylons divert birds from using otherwise popular flight corridors. This measure could be combined with light, noise, or moving devices to potentially increase effectiveness. Meta-analysis of studies where flight diverters have been installed suggests the efficacy of diverters in reducing raptor collisions at power lines (Barrientos et al. 2011), but there is no evidence of the effectiveness of flight diverters on reducing collisions at wind turbines.

Nest management. This measure is intended to reduce eagle activity in the project footprint by modifying outcrops or cliffs to inhibit nest building, removing nest trees, or providing and/or removing suitable nesting substrates. The new Rule defines when permits may be issued for removal of nests: in emergency situations or if the nest creates a functional hazard. Removal is limited to "alternate nests" (formerly "inactive nests"), but removal of "in-use nests" (formerly "active nests") may be permitted prior to egg-laying. An in-use nest is defined as a ''golden eagle nest characterized by the presence of one or more eggs, dependent young, or adult eagles on the nest in the past 10 days during the breeding season.'' Alternate nests are defined as ''one of potentially several nests within a nesting territory that is not an in-use nest at the current time.'' If there is no in-use nest, the Rule states that all nests in the territory are considered ''alternate nests'' (U.S.F.W.S. 2016b).

Adjustments to turbines and turbine operations. These practices typically involve siting of individual turbines and modification of turbine operations in response to perceptions of risk to eagles. There is also increased interest to minimize take through the use of technology that detects eagles and/or alerts eagles to risk or deters them from approaching the turbine area. These practices are described in more detail below.

Curtailment. This strategy can include shutting down operation of specific turbines that are determined to pose a high collision risk. Research on the effectiveness of this measure could be useful for turbine micro-siting at future projects by identifying factors that correlate with collision risk, such as topographic position. De Lucas et al. (2012) evaluated this approach in Spain by selectively stopping turbines that were identified as high-risk, which resulted in a 50% reduction in Griffon Vulture (*Gyps fulvus*) collision fatalities. The principal challenge is identifying problem turbines. Associating a reported eagle fatality with a specific turbine is not always possible, and fatalities of eagles at most wind facilities may be too low for one turbine to "stand out" statistically as a problem turbine.

A second option is shutting down one or more turbines when an eagle is detected approaching those turbines and is presumed to be at risk of collision, a process often referred to as "informed curtailment." This technique has been implemented at several operating projects to avoid collisions of rare and protected species, such as Whooping Cranes (*Grus americana*) or California Condors (*Gymnogyps californianus*), as well as Golden Eagles, and it is a key feature of both the PacifiCorp and Duke plea agreements (United States vs. Duke Energy Renewables 2013, United States vs. Pacificorp Energy 2014)).

This form of curtailment is typically coupled with human observers located in a strategically placed observation tower at the project site. There is considerable interest in developing automated detection technologies to substitute for human observers. Golden Eagles are substantially more abundant than condors and cranes, and curtailment could be more frequent with greater effect on power production, unless eagle activity is refined by linking certain eagle flight behaviors with a higher risk of collision.

Based on a review of minimization activities at six existing projects and in available Eagle Conservation Plans, informed curtailment is a frequently proposed minimization strategy. Proposed projects can implement this minimization option at times of year when pre-construction surveys have indicated that activity and presumably collision risk is higher. Alternatively, this measure could involve establishing a "curtailment buffer" when a nest site is occupied (Tetra Tech 2012).

To our knowledge, none of the six existing projects with available Eagle Conservation Plans accompany informed curtailment with an experimental design evaluating or quantifying its effectiveness. At operating projects where this measure is employed, a robust "pretreatment" estimate of eagle fatalities that would enable a "before–after" comparison of the effectiveness of informed curtailment usually is not available. In addition to "pre-treatment" fatality monitoring, evaluation of informed curtailment would be improved by enhanced fatality monitoring, the goal of which is to increase detection of eagle carcasses by searching more turbines and larger plots. Because eagle carcasses persist (Orloff and Flannery 1992), larger plots can be searched less frequently (e.g., monthly), offsetting the cost of searching more turbines. Therefore, to evaluate informed curtailment, enhanced fatality monitoring should be conducted a minimum of 2–3 yr prior to implementation of curtailment. As stated earlier, a rigorous evaluation of informed curtailment based on changes in fatalities may be precluded due to low levels of fatalities at most projects.

Turbine micro-siting. This measure includes turbine setbacks from ridges and steep slopes and avoidance of high eagle-use areas and flight zones. The decision to implement turbine setbacks would be informed by pre-construction surveys of eagle use and behavior and the orientation of slopes to prevailing winds. Moving turbine locations to avoid areas of high eagle activity has been used at wind project sites in Wyoming (Young et al. 2003) and has been proposed when older turbines are replaced by modern turbines, during repowering at Altamont and in the Draft Environmental Assessments of other proposed projects (e.g., Mohave County Wind Farm, AZ). Recent research describing how Golden Eagles and other raptors use topography during flight also could be applied to micro-siting (Smallwood et al. 2009, Katzner et al. 2012b, Miller et al. 2014). The effects of turbine micro-siting on predicted take can be quantified if pre-construction eagle activity surveys are used to guide micro-siting. If turbine construction is avoided in areas with high eagle activity, exposure could be adjusted and a new take prediction could be calculated.

Deterrence. This measure is based on automated systems that detect and then actively deter eagles from flight paths that are assumed to put them at risk of collision. The deterrents are intended to alert eagles or make them uncomfortable, causing them to change their flight path. The development and application of bird deterrence has a long history (Stevens et al. 2000, Ronconi and St. Clair 2006, De Fusco 2007, WEST 2015); however, a fundamental difficulty with deterrence measures is negative habituation, in which target species learn to ignore the deterrent. Some deterrent systems rely on a combination of audible alerts and dissuasion (May et al. 2012), but there has also been interest in the application of visual deterrents. UV light installed on turbines has been proposed as a potential deterrent for eagles and other raptors, but initial tests indicated no response of multiple eagle individuals and different raptor species to the presence of UV light (Hunt et al. 2015). An analysis of the genome of a Golden Eagle indicated the absence of an allele for UV-light sensitivity (Doyle et al. 2014), supporting the view that design of effective eagle deterrents will benefit from a deeper understanding of eagle physiology and behavior (Sinclair and DeGeorge 2016a).

Evaluating strategies to minimize eagle take. Developing effective technology that detects and deters eagles and thereby reduces collision fatalities is a widely shared goal (United States Department of Energy–Energy Efficiency and Renewable Energy [U.S.D.O.E.–E.E.R.E.] 2016). There are a few commercially available detection and deterrence systems, and radar and camera-based detection systems are in various stages of development and application. These systems generally have not had independent verification of their effectiveness, especially in application to minimizing take of Golden Eagles. Such evaluation should be facilitated by coordinated research on detection and deterrence technologies based on independent, third-party design and implementation, and the public release of results.

Even with relatively large estimated or predicted average take (e.g., 3–4 eagles per yr), interpretation of results of technology evaluation will be complicated by small sample sizes and annual variability. By chance, measured take will often exceed or be lower than the average during a typical research time frame (2–3 yr), especially if the eagle prey base and related eagle activity vary widely. Thus, we strongly recommend coordination of tests and standardization of protocols, especially with respect to data collection that might enable data integration across multiple projects and provide meaningful statistical inferences and robust conclusions (Sinclair and DeGeorge 2016b). Alternatively, other metrics, including evaluation of eagle behavior in response to the deterrent and the use of surrogate species, such as large Buteos (e.g., Red-tailed Hawk [*Buteo jamaicensis*]) may need to be considered for the tests to increase sample size for analysis of effects.

To support the development and review of Eagle Conservation Plans, results from the evaluation of detection and deterrence technologies should be quantified to estimate the reduction of predicted eagle take. This calculation is essential for effective implementation and compliance with the Rule and Guidance, because predicted take that cannot be avoided or minimized, must be offset to accomplish the compensatory mitigation requirement for Golden Eagles.

Minimizing take at Altamont Pass. Altamont has the highest number of Golden Eagle fatalities recorded anywhere in the U.S., and multiple actions, guided by settlement agreements and a Scientific Review Committee (SRC), have been taken to reduce fatalities of Golden Eagles and other raptors (Hunt 2002, Smallwood and Karas 2009, ICF International 2016). These include replacing large numbers of older and low-capacity turbines with fewer, higher capacity turbines (aka repowering), removal of hazardous turbines, and seasonal shutdown of all older-generation turbines. Paradoxically, the high number of Golden Eagle fatalities at Altamont makes evaluating effects of minimization strategies statistically feasible, and this evaluation indicates that each of these measures has been effective in reducing Golden Eagle mortality to some degree (ICF International 2016). For example, the shutdown of all older-generation turbines between November and February achieved the target of 50% reduction of Golden Eagle fatalities, in comparison to baselines set by the settlement agreement and the SRC-recommended baseline (ICF International 2016). Repowering has also been effective in reducing Golden Eagle fatalities and the lessons learned should be applicable at other, older wind projects; knowledge gained about turbine micrositing could be applicable at new projects.

Compensate for Remaining Take. If project developers are unable to avoid or minimize predicted take of Golden Eagles, any remaining take must be offset by quantifiable and verifiable actions that either reduce Golden Eagle mortality from another anthropogenic source, or provide sustained increases in Golden Eagle productivity over the life of the project. Because there are currently no approved minimization measures, all predicted take at a wind energy facility must be offset by a company to be in compliance with its take permit. In the new Rule, the compensation ratio of Golden Eagle take is 1.2 to 1. Several options for offsetting take have been suggested by the Service (U.S.F.W.S. 2016b), and these are discussed below.

Power pole retrofitting. Electrocution on power lines is a major source of eagle mortality (U.S.F.W.S. 2016a), and retrofitting electric power poles to prevent electrocution of eagles is the current option recommended in the Guidance for most wind projects seeking permits (see U.S.F.W.S. 2011, 2014, 2016d). In the Guidance, the Service describes how to use Resource Equivalency Analysis to calculate lost eagle-years due to collision mortality and to estimate the number of poles that need to be retrofitted to offset predicted Golden Eagle take (U.S.F.W.S. 2013). Three eagle take permits have been issued to wind facilities, and all are proposing to use this mitigation strategy to offset permitted eagle take (Shiloh IV, Solano County, CA: predicted take of 0.89 eagles per year, 133 power poles retrofitted; Alta East, Kern County, CA: 0.6 eagles per year, 51–74 power poles retrofitted and Choke Cherry Sierra Madre: 10–14 eagles per year; 1492–3778 power poles retrofitted).

Voluntary lead abatement. Eagles are exposed to lead when scavenging on animal carcasses and gut piles that hunters using lead ammunition leave in the field. Seasonal peaks in blood lead levels associated with game hunting seasons and local exposure to shot game animals have been widely and consistently reported for eagles and other avian scavengers (Kelly et al. 2011, Bedrosian et al. 2012, Cruz-Martinez et al. 2012, Rideout et al. 2012, Harmata and Restani 2013). Direct mortality from lead poisoning has been estimated in several raptor populations and may range from 3–9% (Pattee et al. 1981, 1990, Hunt 2002, Kelly et al. 2011, Harmata and Restani 2013, U.S.F.W.S. 2016a). Programs to reduce lead exposure due to big-game harvest have been attempted in California, Arizona, and Wyoming with measurable results (Sieg et al. 2009, Kelly et al. 2011). Blood lead levels of Golden Eagle and Bald Eagle (*Haliaeetus leucocephalus*) have dropped in response to reductions in the use of lead ammunition even without complete voluntary participation (Kelly et al. 2011, Bedrosian et al. 2012).

Removing roadkill to reduce eagle vehicle strikes. Golden Eagles have been killed by vehicle strikes while feeding on road kill (Kochert et al. 2002). Accurate estimates of the importance of this source of mortality are hard to determine, but various estimates have suggested that eagle deaths from vehicle collisions average approximately 5% of the total amount of annual Golden Eagle mortality

(Hunt 2002, U.S.F.W.S. 2016a). This source of mortality could be substantial (Phillips 1986). The number of carcasses removed, the miles of road to be cleared, or the frequency of carcass removal needed to offset an eagle turbine collision fatality is unknown. A decision framework for estimating mitigation credits from roadkill removal was presented as a compensatory mitigation option in the Mohave County Eagle Conservation Plan, AZ (Tetra Tech 2012).

Managing prey populations to increase eagle productivity. Various studies have suggested that Golden Eagle productivity, defined as the number of fledglings produced per nesting attempt, may be limited by abundance of prey, at least in some parts of Golden Eagle range (Steenhof et al. 1997). Management actions leading to increased eagle productivity within the eagle management unit (U.S.F.W.S. 2016b) may therefore be a viable mitigation option in some areas. Unlike mitigation to reduce mortality, where one can assume a comparable age structure of eagle deaths from wind energy and other mortality sources, increases in eagle productivity need to account for time discounting and age-specific survival rates.

Eagle prey may be limited by top-down factors, such as predation or poisoning, that keep prey abundance below carrying capacity, or by bottom-up factors related to the carrying capacity of the area. Increasing carrying capacity may be limited to areas where vegetation composition and structure will respond to management in the time frame needed to meet the mitigation requirements (e.g., in relatively high precipitation zones). Mitigation to increase productivity will also be challenging due to substantial temporal variation of prey populations, notably Leporids and Sciurids (Gross et al. 1974, Nyström et al. 2006).

Other offset mitigation options. Other potential offset actions can be considered, such as nest-site enhancement. For example, heat stress has been recorded as a significant source of mortality for nestlings in Idaho and providing shading to exposed nests could reduce mortality and increase productivity (Kochert et al. 2002). Such actions may be applicable in specific locations where repeated nest failure and the causes of that failure are known.

Raptor rehabilitation is a common practice and thousands of raptors, including Golden Eagles, have been rehabilitated and released back into the wild. Captive breeding and rehabilitation of eagles injured in ways other than by wind turbine strikes would seem to provide possible options for offsetting eagle take; injuries to eagles struck by wind turbines are typically severe, to the point that birds that survive treatment cannot be released. There are multiple studies documenting reasonably high survival of rehabilitated and captive-bred raptors (Wiemeyer 1981, Martell et al. 1991), but questions remain about the longer-term viability and reproductive success of these birds compared with the wild birds that are killed at wind energy facilities.

Expanding compensatory mitigation options. Additional options suggested by the Service (U.S.F.W.S. 2016b) lack the empirical data and credible models needed to quantify the effects of these mitigation strategies on reducing eagle mortality. To address the challenge of increasing the number of allowed mitigation options, we developed a general approach to model the effectiveness of different options to compensate or offset take of Golden Eagles at wind facilities. Briefly, the stages of model development included (1) selection of a panel of subject matter experts who participated in development and revision of a conceptual model, (2) translation of the conceptual model into a quantitative model by identifying functional relationships, (3) estimation of parameter values for select variables in the functional relationships through a formal, structured elicitation process intended to minimize bias and maximize accuracy, transparency, and utility (Runge et al. 2011), (4) documentation of expert's uncertainty about each elicited parameter value and integrating this uncertainty into the functions, and (5) development of a coded model in MATLAB (version R2012b, MathWorks) and running 5000 simulations of the model followed by sensitivity analysis. Model development and structure for a voluntary lead abatement example (Fig. 1) are described in detail in Cochrane et al. (2015).

To simplify modeling of the relative effectiveness of a mitigation option, such as voluntary lead abatement, we assumed that the age distribution of eagles saved parallels those of eagles taken, and we assumed that the mitigation occurs in the same time frame as actual take. Thus, no age structure conversion or time discount for delayed offsets were incorporated into the modeling effort. The model incorporates the uncertainty in eagle density estimates and the modeled mortality rates caused, for example, by lead ingestion.

All mitigation models require monitoring and experimental research that target the most tenuous assumptions and parameters built into the model to test confidence in the model's predictive ability, and this process is facilitated by sensitivity analysis. Application of the model can be tailored depending on the scenarios under consideration. For example, a wind developer might want to know what percentage of participation by big-game hunters in a voluntary ammunition-switching program is needed to offset a specific level of take to satisfy permit requirements.

Implementing compensatory mitigation. A general scenario for accomplishing offset mitigation is that individual project developers would arrange for the actions proposed for offsetting predicted eagle take (e.g., arranging for the retrofitting of the required number of power poles) or, in the case of other options, setting up programs for roadkill removal, voluntary lead abatement, or habitat improvement. There are inefficiencies in this approach, and the scale of offset mitigation needed (i.e., one eagle per year) may not justify setting up myriad mitigation programs administered by multiple wind developers and operators.

As one alternative, the National Fish and Wildlife Foundation has established an Eagle Mitigation Account to which wind companies can contribute for power pole retrofitting (Alta East eagle permit, U.S.F.W.S. 2016d). Mitigation banking, or *in lieu* fee credit programs, may also provide an alternative and possibly more efficient and effective structure for accomplishing eagle take offsets, and in the revised Eagle Rule, the Service has indicated an interest in developing these options for offsetting eagle take (U.S.F.W.S. 2016b).

As typically organized, a mitigation "banker" sets aside or manages a landscape to enhance or restore ecosystem function or other values by providing purchasable credits for developers who need to offset impacts to similar landscapes. An eagle mitigation bank would be structured similarly, although focusing on managing a landscape to improve eagle survival and productivity. For example, an individual landowner or consortium of landowners controlling management of large tracts of land could reduce lead inputs by limiting access to non-lead ammunition hunters, by conducting an active roadkill removal program, ending Sciurid control programs, and by enhancing or restoring habitat for eagle prey. As required by the Service's mitigation recommendation for Golden Eagle, the "bankers" would have to quantify the mitigation credits available for sale to wind project developers needing to offset predicted eagle take. The Service has shown interest in third-party mitigation programs, such as mitigation banks or *in lieu* fee program, but as yet no guidelines have been developed for such programs (U.S.F.W.S. 2016b).

CONCLUSIONS

The Service has concluded that the global Golden Eagle population is limited by anthropogenic mortality (U.S.F.W.S. 2016a), and any additional mortality could lead to a population decline inconsistent with the preservation standard set by the Service in the revised Eagle Rule (U.S.F.W.S. 2016b). Thus, any permits to take Golden Eagles at wind facilities must accomplish "no net loss" through implementation of actions to avoid, minimize, or offset the predicted take. As this review indicates, there are many actions a wind energy company could implement that theoretically could accomplish the requirement of the take permit, but additional empirical data evaluating their effectiveness is needed. We currently cannot evaluate whether the mitigation actions are achieving the conservation goal of offsetting Golden Eagle take, or whether wind energy companies are under- or over-mitigating.

The relatively low number of eagles reportedly taken or predicted to be taken at individual wind energy facilities complicates our ability to evaluate the effectiveness of potential mitigation actions, and we have suggested a collaborative and coordinated approach to research that facilitates data integration across multiple projects. Research to evaluate strategies that reduce eagle take also may be hampered by the constraints associated with working at operational wind facilities. Wind facilities are power plants, not research sites and thus, research evaluating mitigation actions, such as the use of new technologies to help minimize take, may face constraints on experimental design, such as randomly assigning treatments.

Experimental evaluation of the effects of curtailment and detection and deterrence technology on eagle take is further complicated by the legal protection provided Golden Eagles. Research designs may be constrained by permits that require wind companies do all they can to mitigate predicted take, thus limiting the use of proper controls. Wind companies may also be reluctant to offer sites for research without the legal protection afforded by take permits. Plea agreements and civil settlements may expand the number of wind facilities available as study sites, but eagle activity may not warrant use

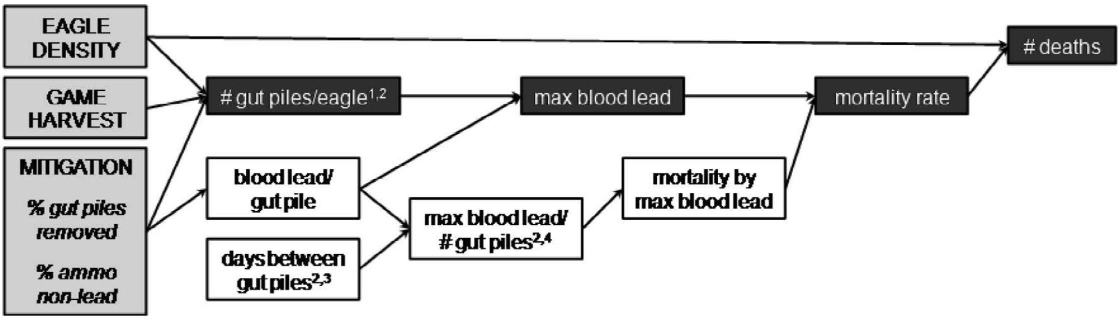

Figure 1. Causal diagram illustrating the cause-to-effect relationships (directional arrows) between input and output parameters (boxes) in the Golden Eagle lead abatement model as adapted from Cochrane et al. 2015. The inputs (light shaded boxes) are set for each scenario and geographical unit modeled. The subsequent parameters or response variables result from the modeling steps; of these, the dark boxes are location-specific responses (dependent upon the gut piles available per eagle). Four additional model inputs are indicated by superscript numbers where they influence a response parameter: (1) the game recovery rate, (2) maximum number of gut piles scavenged per month, (3) minimum days' lag between gut piles scavenged, and (4) daily blood lead decay rate derived from the blood concentration half-life. The model output is a probability distribution of Golden Eagle deaths produced from repeated stochastic simulations.

of these sites for research. The availability of research permits could improve this situation, but, to the best of our knowledge, the Service does not offer the option of a research permit that provides legal coverage—a project would also need an eagle take permit.

A clear framework for incorporating research results into siting decisions and operations is also needed. Even as new results are reported in the scientific literature, substantial uncertainty exists regarding how these new results will affect the eagle permitting process. For example, how many tests of a minimization strategy or technology are needed before it becomes a Best Management Practice under the current rule? Similar challenges exist for updating the Service's Bayesian take prediction model or for adding to the options for compensatory mitigation. For the latter, we briefly described our use of expert elicitation to quantify the benefit of different options for offsetting predicted eagle take. The resulting models are hypotheses whose structure and parameters need to be evaluated with empirical data, but sensitivity analyses of the models can guide the research by identifying key variables to evaluate and improve the accuracy of the models and the potential effectiveness of the mitigation options.

In the meantime, the climate continues to warm from anthropogenic activity that includes the burning of fossil fuels to generate electricity, and the response of species to this warming is detectable. The new D.O.E. Wind Vision articulates a goal of a major expansion of installed wind energy capacity by 2030 as a key part of the strategy to reduce greenhouse gas emissions (U.S.D.O.E. 2015). As we strive to achieve these emissions reductions, there is concern that the growth of wind energy will substantially increase the threat to both Bald and Golden eagles. Alternatively, fully realizing wind energy's contribution to emission reduction goals will be limited until we accomplish the goal of reducing the collision risk to eagles.

This challenge of simultaneously reducing greenhouse gas emissions while achieving species' conservation goals is one faced not only by state and federal agencies with the responsibility of enforcing laws to protect trust species, but also by all stakeholders interested in wildlife conservation. Our ability to achieve these goals will be enhanced by a collaborative approach to both conducting research and resolving the structural challenges (Allison et al. 2014). Examples of this approach exist, including the National Wind Coordinating Collaborative, the Bat Wind Energy Cooperative, and the American Wind Wildlife Institute. These collaborative efforts demonstrate a commitment of all participants to achieving the conservation benefits of wind energy while mitigating its impacts to wildlife.

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