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GOLDEN EAGLES IN A CHANGING WORLD

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In recent years, Golden Eagles (*Aquila chrysaetos*) have emerged as a conservation concern in the United States, particularly in the West. Our nation's effort to become more energy independent has involved a significant expansion in the development of domestic sources of both renewable and nonrenewable energy. The influence of energy development, particularly wind energy, taken together with other anthropogenic sources of mortality, including electrocution on power distribution lines, contaminants, collisions with vehicles, and illegal shooting, may be resulting in declining Golden Eagle populations (U.S. Fish and Wildlife Service [U.S.F.W.S.] 2016a). To achieve the objective of "stable or increasing breeding populations" promulgated under the Bald and Golden Eagle Protection Act (Eagle Act; 16 U.S.C. 668-668d) and appurtenant regulations (U.S.F.W.S. 2009, 2016b; hereafter Eagle Rule), the U.S.F.W.S. will require a greater understanding of Golden Eagle population dynamics, movement patterns, and genetic connectivity across populations, and conservation practices that reliably reduce or mitigate population limiting factors (U.S.F.W.S. 2016a, 2016b). In addition, state, federal, and tribal wildlife and land management agencies need this information to support conservation planning for Golden Eagles at local and regional scales.

To support the dissemination of new information on the demography, nesting ecology, movement patterns, diet, and conservation of Golden Eagles, the Academy for the Environment, University of Nevada, Reno, and Western Golden Eagle Team, U.S. Fish and Wildlife Service, collaborated to host a symposium at the 2015 annual conference of the Raptor Research Foundation (RRF), in Sacramento, California. Invited speakers presented new information during three sessions that focused specifically on Golden Eagle demography and population trends, use of innovative research technologies and techniques, and conservation planning. Six of the presenters subsequently developed manuscripts published in this special issue.

The California–Nevada Golden Eagle Working Group convened a meeting immediately prior to the RRF meeting in Sacramento, where they hosted a symposium that focused on Golden Eagle prey ecology and the need for using consistent terminology in raptor ecology. Two of the invited presenters subsequently developed manuscripts that also appear in this special issue; one of these discusses the use of terminology in describing reproduction, the other summarizes spatial and temporal patterns in eagle diets throughout the western U.S.A.

Four additional manuscripts, not associated with these symposia, are also included in this special issue, since they address issues highly relevant to Golden Eagle conservation and management. These papers address several different topics, including

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religious take, lead and anticoagulant rodenticides, electrocution, and dispersal and survivorship of young eagles.

The contributions in this special issue address a wide range of subjects, but can be organized according to their potential role in contemporary conservation planning and modeling for Golden Eagles. Several papers describe research into local or regional factors influencing Golden Eagle survival and fecundity, and management practices proposed to mitigate negative effects. Other studies, conducted at larger scales, examine how patterns of movement and migration determine seasonal distribution of individuals and subsequently influence genetic structure of populations. Finally, aided by recent advances in computing power and GIS capabilities, researchers can incorporate information from multiple scales into spatially explicit population models that enable evaluation of eagle population responses to changes in resources, risk factors, and management strategies.

Factors Influencing Survival and Reproduction. Anthropogenic sources of mortality exert a substantial negative influence on Golden Eagle survival, causing 56% of estimated annual mortality across all age classes (U.S.F.W.S. 2016b). Exposure to contaminants constituted 15% of estimated annual mortality and was the largest single anthropogenic source of mortality (U.S.F.W.S. 2016b). A contribution to this issue by Garth Herring and colleagues provides a comprehensive review of lead and anticoagulant rodenticides in Golden Eagles. The authors describe sources of lead and rodenticides in Golden Eagle habitats, exposure routes and toxicity, and subsequent potential impacts to individual eagles and populations. The authors point out that substantial advances in our understanding of contaminant sources, exposure rates, and physiological effects to individuals have occurred, but quantifying population effects remains elusive.

Golden Eagle productivity is influenced substantially by the distribution and availability of prey resources (Steenhof et al. 1997), and management of prey resources has been proposed as a mitigation method to offset some anthropogenic mortalities (U.S.F.W.S. 2016a). Quantification of eagle diets and the relationships between prey resources and productivity are therefore important to enable identification and prioritization of prey species for management. In this issue, Geoffrey Bedrosian and eight coauthors reviewed published and contemporary diet studies, and analyzed previously unpublished data, to evaluate factors that may drive Golden Eagle prey selection in the western U.S.A. They found that in much of the Golden Eagle's western range, the proportion of leporids in the diet was the driving factor for overall diversity of prey and percentage of other prey groups in the diet. Diet and dietary breadth varied geographically, however, with sciurids dominating the diet in areas where leporid populations were absent or depressed. The authors attributed these dietary differences to regional and temporal differences in prey communities available to eagles, suggesting that management of prey habitat should be tailored to local environmental conditions and prey communities.

Chuck Preston and colleagues examined the relationships between the abundance of primary prey and both diet breadth and reproductive rate of Golden Eagles in Wyoming's Bighorn Basin. During their 2009–2015 study, the authors found that dietary breadth increased, and eagle productivity decreased, during years when cottontail rabbit populations were low. Although this finding highlights the importance of maintaining habitats for cottontails, the authors also suggest that active management to recover white-tailed jackrabbit and white-tailed prairie dog populations may be important to buffer Golden Eagles from fluctuations of primary prey.

The oral histories of multiple indigenous North American tribes indicate that direct removal of Golden Eagle nestlings has long been practiced. To evaluate potential effects of this practice on Golden Eagle productivity, Dale Stahlecker and three colleagues analyzed 9 yr of occupancy and productivity data from three study areas on the Navajo Nation: one where Hopi harvested nestlings annually and two where no removals occurred. They found similar patterns of occupancy and numbers of early-season nestlings, but significantly fewer nestlings reached fledging age in the harvested area. Given current concerns over the status of Golden Eagles throughout the West, the authors recommended continued monitoring of this population to better understand the effects of Hopi harvests on eagles nesting on the Navajo Nation.

The important role of anthropogenic mortality as a driver of Golden Eagle population trends supports increasing concern over the cumulative effects of energy development, particularly the rapid expansion of wind energy in eagle habitat (U.S.F.W.S. 2016b, Millsap et al. 2013). To achieve the objective of "stable or increasing breeding populations" promulgated under the Eagle Act, the U.S.F.W.S.

has established a robust strategy for eagle conservation that allows wind energy companies to comply with the Eagle Act by obtaining incidental take permits. In this issue, Taber Allison and three colleagues provide an overview of the U.S.F.W.S. strategy for avoiding, minimizing, and mitigating predicted eagle collisions with wind turbines, and describe their efforts to model the effects of offset mitigation (e.g., lead remediation, removal of animal carcasses from roadways, enhancement of prey resources) in order to calculate mitigation credits. The authors also point out some of the scientific and logistical challenges to implementing the U.S.F.W.S. strategy, and recommend a collaborative, multi-stakeholder approach to conducting research and expanding the options available for mitigating eagle mortality associated with wind turbines.

Modifying electric distribution poles to reduce or eliminate the risk of electrocution to Golden Eagles is currently recognized by the U.S.F.W.S. as the most practicable and best-quantified method available for compensatory mitigation under the Eagle Rule (U.S.F.W.S. 2013). Electrocution of eagles and other raptors on retrofitted poles persists, however, when structural modifications are made incorrectly. In this issue, James Dwyer and colleagues describe retrofitting errors made on 52 poles described as retrofitted where 56 birds (including 17 Golden Eagles) were electrocuted. They categorized errors as product design error, mitigation plan error, or application error, and identified specific structural issues responsible for post-retrofitting fatalities. The authors suggest that utilities use this information to identify and proactively correct improperly retrofitted poles, and to improve the effectiveness of retrofitting programs overall.

Movement, Migration, and Genetic Structure of Populations. Patterns of dispersal and migration exhibited by Golden Eagles are important determinants of seasonal distribution and exposure to threats, and likely influence the genetic structure of North American populations. Jessi Brown and 20 colleagues summarized telemetry data from 571 Golden Eagles to examine movement patterns on a continental scale, and compared the observed patterns of use to four currently used ecological and administrative mapping systems (i.e., Bird Conservation Regions (BCRs), Migratory Bird Joint Ventures, Landscape Conservation Cooperatives, and U.S. administrative migratory bird flyways). The very large sample size achieved in this study provided detailed landscape-scale information on the movement patterns of Golden Eagles and how they conformed to the administrative landscape.

Dispersal by young Golden Eagles is an important aspect of their life history and may have significant effects on recruitment and survivorship. Robert Murphy and six colleagues reported on the movements of 66 pre-breeding age Golden Eagles monitored from 2010–2015, in the Colorado Plateau and southern Rocky Mountains. Using satellite telemetry, they documented the timing and distance of dispersal, and survival of first-year eagles, as well as changes in home-range size between their first and second year. Most telemetered eagles stayed within 120 km of their natal nest, where they experienced higher survivorship than did their counterparts traveling longer distances (>500 km).

The high mobility and diversity of movement patterns exhibited by Golden Eagles presents a challenge for delineating populations and establishing management units. Seeking to describe biologically meaningful population boundaries, Ron Van Den Bussche and three coauthors developed a new Golden Eagle genome reference and conducted genomic sequencing for 32 eagles from across western North America. They found genetic variation was partitioned into three groups: a northern group (Alaska and British Columbia) and two distinct groups in the western U.S.A. Although preliminary, these results represent significant progress toward the management objective of achieving a cost-effective way to assign eagle fatalities of unknown origin to their natal geographic area.

Population Modeling. Species conservation is increasingly reliant on population models to estimate population trends and to quantify and predict the factors that influence population sustainability. Population models also play an important role in the Service's implementation of the Eagle Act by enabling estimation of population size and sustainable harvest rates (U.S.F.W.S. 2016b). Jason Tack and his colleagues used a life-stage simulation analysis to examine what life history characteristics most affected population growth of Golden Eagles. Their model indicated that breeding adult survival most affected population growth and that even small reductions in breeding adult survival (<4.5%) caused population declines. Moreover, they found Golden Eagles to be limited in their ability to offset these declines in survivorship by increasing reproductive output. Using a spatially explicit, individually based population model (HexSim), David Wiens and colleagues explored the influence of habitat

quality and distributions, prey resources, and threats on Golden Eagle movement, reproduction, and survival in the Mojave Desert region. Their model results were consistent with the findings of Tack and colleagues in that adult survival had a disproportionate effect on population size; however, the HexSim model indicated that survival rates of subadult eagles also had a substantial effect. The model suggested that increases in mortality associated with renewable energy structures could adversely impact populations, but that site-specific actions could reduce those effects.

Terminology. Using clear, consistent terms when reporting research findings is essential for effective communication. Using terms inconsistently or not appropriately defining them can make comparison of results across studies difficult or misleading. Karen Steenhof and her three coauthors review terminology commonly used in describing raptor nesting ecology and both make and reaffirm some prior recommendations for standardizing the use of several terms used in raptor biology.

The goal of this collection of reports is to share the results of recent and newly emerging research on Golden Eagle populations, review human-caused mortality factors and approaches for managing their effects, and provide some guidance on how to better communicate results to other researchers and decision-makers. We thank all of the authors for their contributions to this effort, and their commitment to Golden Eagle conservation.

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