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RESEARCH ARTICLE

Efficacy of non-lead ammunition distribution programs to offset fatalities of golden eagles in southeast Wyoming

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Abstract

Golden eagles (*Aquila chrysaetos*) face many anthropogenic risks including illegal shooting, electrocution, collision with wind turbines and vehicles, and lead poisoning. Minimizing or offsetting eagle deaths resulting from human-caused sources is often viewed as an important management objective. Despite understanding the leading anthropogenic sources of eagle fatalities, existing scientific research supports few practical solutions to mitigate these causes of death. We implemented a non-lead ammunition distribution program in southeast Wyoming, USA, and evaluated its effectiveness as a compensatory mitigation action to offset incidental take (i.e., fatalities) of golden eagles at wind energy facilities. In 2020 and 2022, we distributed non-lead ammunition to 699 hunters with big-game tags specific to our >400,000-ha study area. These hunters harvested 296 pronghorn (*Antilocapra americana*), 14 deer (*Odocoileus* spp.), and 33 elk (*Cervus canadensis*) in the study area, which accounted for 6.9% and 6.5% of the harvest in these hunt units in 2020 and 2022, respectively. We used road surveys in 2020 to estimate a density of 0.036 (95% CI = 0.018–0.058) golden eagles/km^2 during the big game hunting season in our study area. Model output suggests that our non-lead ammunition distribution program offset the fatality of 3.84 (95% CI = 1.06–23.72) eagles over the course of these 2 hunting seasons. Our work illustrates the potential usefulness of non-lead ammunition distribution programs as an action to mitigate eagle fatalities caused by wind facilities or other anthropogenic causes of death.

KEYWORDS

Aquila chrysaetos, compensatory mitigation, lead abatement, wind energy

Wind power has expanded over the past 2 decades and wind turbines have caused fatalities of golden eagles (*Aquila chrysaetos*; Katzner et al. 2020). In the United States, golden eagles are federally protected under the Bald and Golden Eagle Protection Act, which prohibits take of golden eagles but also authorizes the United States Fish and Wildlife Service (USFWS) to permit take of eagles in circumstances where it is "compatible with the preservation of the bald eagle or the golden eagle" (USFWS 1959). The USFWS can permit take if such authorization is determined to be consistent with their stated goal of maintaining stable or increasing populations of golden eagles (Millsap et al. 2022). Because of the uncertainty surrounding the stability of golden eagle populations, the USFWS has determined that no additional take can be authorized without compensatory mitigation designed to offset authorized take with a reduction of ongoing eagle fatalities from another source. To ensure consistency with population goals, such mitigation must offset 1.2 golden eagles for every 1 eagle for which take is authorized (USFWS 2016).

For the past several years, retrofitting power poles has been the only USFWS-approved option for compensatory mitigation of eagle take (USFWS 2013, 2016*a*, 2016*c*). Additional mitigation options that have been considered include removal of road-killed wildlife to reduce collisions of scavenging eagles with vehicles, habitat-based conservation banks, and support of rehabilitation of injured eagles (Allison et al. 2017, Slater et al. 2022). Furthermore, a recent revision of the Eagle Rule lists lead abatement as an approved mitigation action (USFWS 2024). Despite this, to our knowledge, there has not yet been a lead abatement project implemented for this purpose.

Lead poisoning from spent ammunition is an important cause of mortality and morbidity of golden eagles (Franson and Russell 2014; Ecke et al. 2017; Slabe et al. 2020, 2022; Domenech et al. 2021). Furthermore, multiple studies have illustrated mechanisms for and benefits to avian scavengers from reduced use of lead ammunition (Sieg et al. 2009, Kelly et al. 2011, Bedrosian et al. 2012). Effective lead abatement programs could be used to offset incidental take of eagles in geographic proximity to developments where eagle take permits have been approved (Cochrane et al. 2015). However, for a conservation action to meet USFWS requirements of compensatory mitigation, the number of eagle fatalities reduced from that action must be quantifiable and backed by the best available science (USFWS 2016*a*).

Although the effectiveness of increased use of non-lead ammunition as a form of mitigation has been quantified in a theoretical model (Cochrane et al. 2015), such programs have not yet used empirical data that can assess their real-world feasibility. The mitigation model of Cochrane et al. (2015; Cochrane model) was developed specifically for golden eagles in Wyoming, USA, and it allows for the theoretical estimation of the number of eagle fatalities avoided if a given quantity of non-lead ammunition is used in the place of lead ammunition. Although the model is generalized, it requires 2 key site-specific inputs: the amount of lead ammunition replaced with non-lead ammunition and used by successful hunters, and the estimated density of golden eagles using the area where the harvesting took place.

The objective of this study was to develop and evaluate a compensatory mitigation program to offset fatalities of golden eagles. We assessed if a mitigation program that provided non-lead ammunition to hunters would be logistically feasible and effective using harvest data from participants and estimates of eagle abundance to model the number of eagle fatalities avoided through the program.

STUDY AREA

Our study occurred during the 2020 and 2022 fall hunting seasons in an area located approximately 100 km south of Casper, Wyoming. The study area consists of >400,000 ha of grasslands (examples of common species include western wheatgrass [*Pascopyrum smithii*], Indian ricegrass [*Orzhyopsis hymenoides*], and bluebunch wheatgrass [*Pseudoroegneria spicata*]), sagebrush steppe (*Artemisia* spp.), aspen woodlands (*Populus tremuloides*), and coniferous forest (examples of common species include juniper [*Juniperis* spp.], pine [*Pinus* spp.], and Douglas-fir [*Pseudotsuga menziesii*]). The land is owned by a mixture of private and public entities, where public land is managed for recreation and natural resource extraction by the Bureau of Land Management and the State of Wyoming and private land is managed for agricultural use. The climate in southeast Wyoming is cold and temperate with annual temperatures averaging 9.3°C. The study area has variable topography with elevations ranging from approximately 2,000–2,400 m.

We selected this study area because of the local abundance of golden eagles and energy development, it has a high density of big game hunters, and the Cochrane model was specifically developed for Wyoming (Figure 1). The boundaries of our study area are those of big game hunt areas defined by the Wyoming Game and Fish Department. Elk (*Cervus canadensis*) hunt areas in the study area include hunt area 16 (both years) and 114 (2020 only, was merged with hunt area 16 in 2022), pronghorn (*Antilocapra americana*) hunt areas include 43, 46, and 47, and mule deer (*Odocoileus hemionus*) and white-tailed deer (*Odocoileus virginianus*) hunt areas include 70 and 74 (https://wgfd.wyo.gov/Hunting/Hunt-Planner, accessed 1 Mar 2020). Hunting season dates differed by species and hunt area, but the first firearm seasons began in mid-August and the last ones continued through the end of January.

METHODS

Non-lead ammunition distribution program

For our study, we contacted hunters who drew limited quota tags for the hunt areas mentioned above. We identified those hunters by submitting a public records request for hunter information to the Wyoming Game and Fish Department. To alert hunters to our program, we sent them a postcard via United States mail. The postcard notified them that they qualified to receive 2 free boxes of non-lead ammunition, provided them information on our research project, and pointed them towards a project-specific website we created to facilitate ammunition distribution (www.huntersforeagleconservation.org). The website had additional information on the project, provided a portal to receive free ammunition through a third-party ammunition retailer, and allowed us to track the number of boxes of ammunition distributed to hunters. Each eligible hunter was given a unique code for purchase of ammunition that verified their eligibility.

The only requirement we asked of hunters receiving free ammunition was to agree to participate in a survey after the hunting season was complete. Some hunters who accepted ammunition and filled out the survey after the first year of our program also drew a license in an eligible hunt area in the second year of the program. We contacted these hunters at the start of the second year via email to encourage their continued participation.

We used an incentive-based approach with minimal outreach partly based on previous successful methods used to encourage hunters to voluntarily use non-lead ammunition (Katzner et al. 2024). Specifically, we created a message that was simple, positive, focused on leveraging the conservation ethic of hunters, and that did not disguise our research and conservation goals. We straightforwardly informed hunters of our objective to test the efficacy of voluntary non-lead ammunition programs to reduce eagle fatalities.

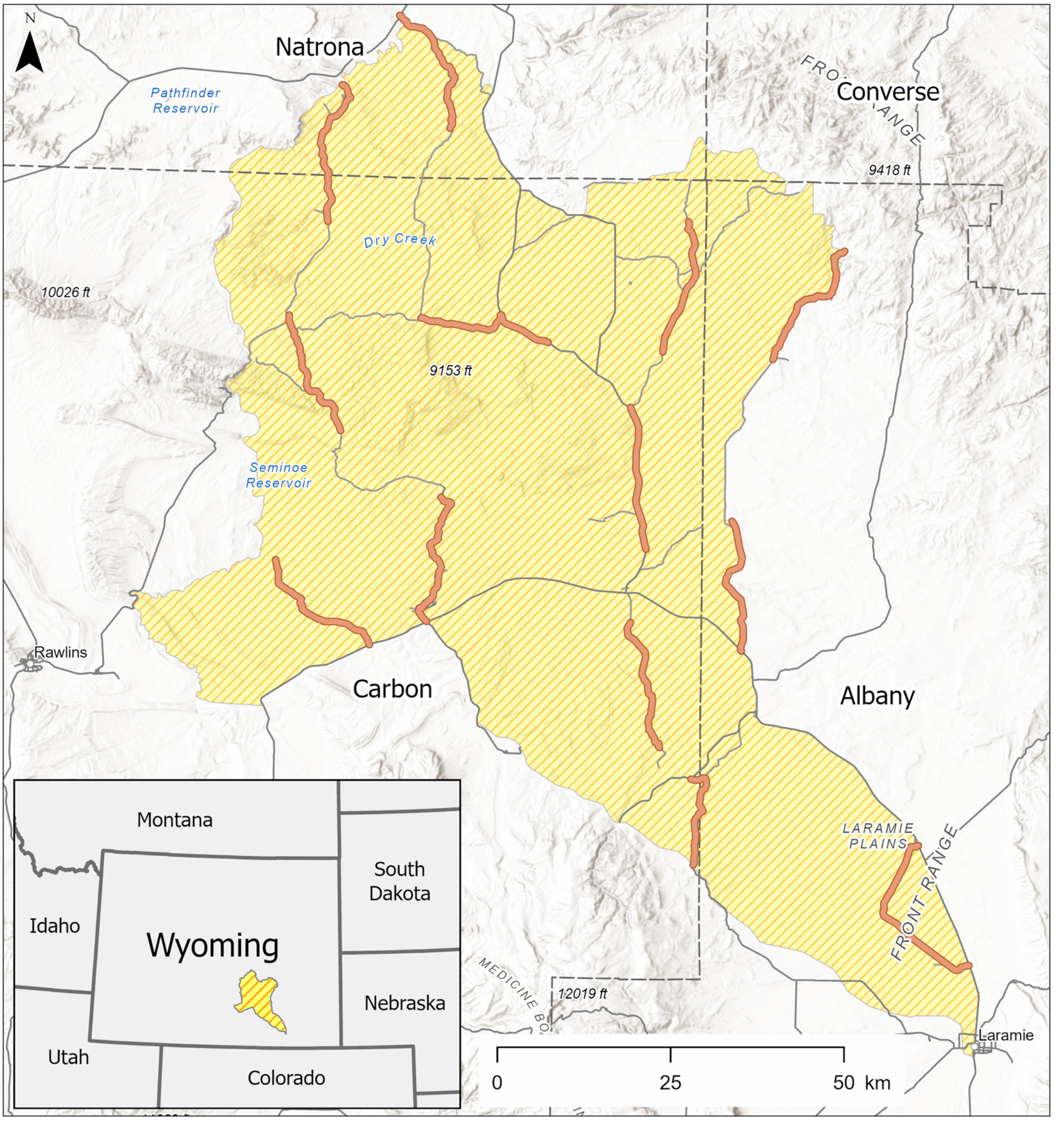

FIGURE 1 Study area boundary (yellow) for a non-lead ammunition distribution program conducted in southeast Wyoming, USA, in 2020 and 2022 consisting of multiple big game hunting areas and road transects (orange) completed for golden eagle abundance surveys. Counties are shown in bold.

Quantification of big game harvest

We obtained hunt area and species-specific harvest information for the 2020 and 2022 hunting seasons from the Wyoming Game and Fish Department website (https://wgfd.wyo.gov/hunting-trapping/harvest-reports-surveys, accessed 15 May 2023). To estimate harvest with the ammunition we provided, we used SurveyMonkey (www.surveymonkey.com, accessed 20 Mar 2023) to conduct follow-up surveys of all hunters that were given free non-lead ammunition. We contacted all participating hunters via email and provided them with a link to the survey; we reminded hunters up to 3 times to take the survey. The survey asked 14 questions (available in Supporting Information). In general, questions focused on each hunter's use of non-lead ammunition, if they were successful in harvesting an animal, what specific big game animal(s) they harvested, what hunt area or areas they were successful in, and whether they would consider participating in a similar program in the future. The survey was short to increase probability of participation but also detailed enough for a robust quantitative assessment of our program.

Estimating density of golden eagles

We used distance sampling to calculate density of golden eagles in the study area for that parameter of the theoretical model (Cochrane et al. 2015). From a database of publicly accessible roads, we used a stratified random sampling design to select 13 drivable survey routes, each 15–27 km long. Two observers drove survey routes at <32 kph during daylight hours from 8–10 October 2020. When we observed a golden eagle perched or flying, we stopped and used a laser rangefinder to measure perpendicular distance from the road to the bird. We recorded all golden eagles observed and we did not limit detection distance.

We developed distance functions to estimate the abundance of golden eagles in the study area (package Rdistance in R; R Core Team 2022, McDonald et al. 2023). We estimated density with a simple null model with a half-normal likelihood distribution because habitat was consistent on the survey routes and there were no covariates of interest or that we predicted would affect eagle detections. Because the Cochrane model requires input of eagle density per unit area, we estimated eagle density/km^2. We assumed that the density estimate derived from our road survey was indicative of golden eagle density in our study area during the hunting season and that the eagle density did not differ between the 2 years of the program (Nielson et al. 2014).

Estimating numbers of fatalities avoided

We used the Cochrane model to estimate the reduction of eagle fatalities in the study area separately for each year of the study (i.e., we implemented 2 model runs). The model parameters Cochrane et al. (2015) used were either estimated using expert elicitation or quantified using hunter harvest totals and eagle density. The parameters estimated by expert elicitation are described in detail in Cochrane et al. (2015, appendix C). Briefly, they include estimates for the number of gut piles eaten per eagle, blood lead concentration increase per gut pile consumed, days between multiple gut piles scavenged, maximum blood lead quantity per gut pile scavenged, mortality by maximum blood lead concentrations, and expected blood lead mortality per site. Because the expert elicitation parameters were established for golden eagles specific to Wyoming, we used these pre-defined parameters in our model runs. The Cochrane model includes a formal sensitivity analysis that evaluates how their model responds to variation in input parameters. We used the same parameters for our model runs and the output of our analyses suggested sensitivities nearly identical to those reported in Cochrane et al. (2015, table 4, appendix D).

We input 2 types of data that were different from those used by Cochrane et al. (2015). First, we used distance sampling to estimate eagle densities in our study area. Second, we used year-specific estimates of hunter harvest for the hunt units in our study area. We used our post-hunt survey to estimate the number of animals harvested with non-lead ammunition by participants of our program. The model estimates the relative monthly reduction in eagle mortality rates and we assumed that reduction was constant across the 5.5-month hunting season. We calculated confidence intervals as the 2.5 percentiles (upper and lower) of the bootstrapped simulations from the Cochrane model. Like Cochrane et al. (2015), we also assumed that all hunters who did not participate in our program used lead ammunition.

RESULTS

Non-lead ammunition distribution program and quantification of harvest

In 2020, we contacted 1,374 hunters via postcard. In 2022, we contacted 750 hunters: 459 via postcard and 291 via email (email recipients were those who had both participated in the program in 2020 and completed a post-hunt survey). Overall, 31.6% (n = 434) and 35.3% (n = 265) of those we contacted participated in the program in 2020 and 2022, respectively. We distributed 1,398 boxes of ammunition to these hunters over the 2 years of the program. Of the participants, 67.1% (n = 291) and 67.2% (n = 178) responded to the email survey in each year and 84.5% (n = 246) and 83.7% (n = 149) of respondents reported hunting with the non-lead ammunition we provided.

Of those respondents who used the non-lead ammunition we supplied, 68.6% (n = 169) in 2020 and 75.2% (n = 112) in 2022 harvested ≥1 animal in our study area. Some also harvested additional animals outside of the study area with the non-lead ammunition we provided. Participating hunters used the non-lead ammunition we provided to harvest 343 animals in the study area. Harvested animals included 20 and 13 elk, 6 and 8 mule deer, and 171 and 125 pronghorn (Table 1) in 2020 and 2022, respectively. The resulting non-lead harvest accounted for 6.9% and 6.5% of the total harvest in study area in 2020 and 2022.

Golden eagle density and estimated reduction in mortality

We surveyed for golden eagles along 13 routes covering 277 km of road on 8–10 October 2020 (Figure 1). We observed 36 golden eagles. From these survey data, our distance sampling models estimated the golden eagle density in the study area to be 0.036 (95% CI = 0.018–0.058) golden eagles/km^2, or 279.20 total individuals (95% CI = 139.60–449.82).

If none of the hunters in the study area used non-lead ammunition, the Cochrane model estimated 5.79 (95% CI = 1.58–35.54) and 4.51 (95% CI = 1.26–28.08) golden eagle fatalities from use of lead ammunition per month in the 2020 and 2022 hunting seasons. Over the 5.5-month hunting seasons in 2020 and 2022, this translates into 31.84 (95% CI = 8.69–195.47) and 24.81 (95% CI = 6.93–154.44) fatalities of golden eagles caused by use of lead ammunition.

TABLE 1 The number of big game animals harvested per hunt unit and the number and proportion of large game harvested with non-lead ammunition per species and year in southeast Wyoming, USA, as a result of a non-lead ammunition distribution program in 2020 and 2022. Hunt unit 114 was combined with hunt unit 16 for the 2022 hunting season; thus, there was no separate total for that unit in 2022.

		Hunt unit								Non-lead harvest	
Year	Species	16	43	46	47	70	74	114	Total harvest	n	%
2020	Elk	457						135	592	20	3.4%
	Mule deer					226	48		274	6	2.2%
	Pronghorn		799	363	822				1,984	171	8.6%
	All species								2,850	197	6.9%
2022	Elk	471						–	471	13	2.8%
	Mule deer					219	34		253	8	3.2%
	Pronghorn		245	108	1,155				1,508	125	8.3%
	All species								2,232	146	6.5%

In 2020, when using the data we collected, the Cochrane model suggested that implementation of our non-lead ammunition distribution program had resulted in an estimated reduction of 0.41 (95% CI = 0.11–2.49) golden eagle deaths per month. Over the 5.5-month hunting season, this translates into 2.23 (95% CI = 0.61–13.68) fewer fatalities of golden eagles. In 2022, the non-lead ammunition distribution program resulted in an estimated reduction of 0.29 (95% CI = 0.08–1.83) golden eagle deaths per month. Over the hunting season, this translates into a reduction of 1.61 (95% CI = 0.45–10.04) fatalities of eagles. Therefore, the 2-year non-lead ammunition distribution program resulted in a model-estimated reduction of 3.84 (95% CI = 1.06–23.72) fatalities of golden eagles.

DISCUSSION

Output from the Cochrane model suggests programs that distribute non-lead ammunition to remove lead from hunted big-game carcasses can be a realistic and effective form of compensatory mitigation to offset fatalities of golden eagles. The number of hunters we contacted, the strong rates of participation, and the substantial estimated reduction in eagle fatalities suggest that the Cochrane model can be a useful tool for evaluating such a reduction in Wyoming. Given the lack of lead mitigation projects for eagles that are currently in place and the substantial interest among stakeholders in developing novel mitigation options for take of golden eagles, our results indicate that programs providing lead-free ammunition are useful and would be effective.

Hunters were extremely receptive to these methods and our programs were so successful that the demand for participation surpassed available funding. We believe that we could have easily increased the number of participants if we had funds to support purchase and shipment of more ammunition. There were 2 instances where potential participants initially provided negative feedback to our outreach. In both of those instances, we were able to contact those hunters individually and address their concerns. Both of these hunters ultimately participated in the program and ordered free ammunition.

The proportion of the big game harvest that resulted from our ammunition distribution efforts was large enough for the model to predict a reduction in eagle fatalities in the study area; however, the wide confidence intervals around our estimated reductions may constrain the management value of this work. Also, we specifically chose an area with a high density of golden eagles and high harvest rates of big game. If eagle density and harvest rates had been lower, we would have needed to distribute non-lead ammunition to more hunters to reach similar predicted levels of decreased mortality. This may be an important consideration for those who wish to implement similar programs in other locations.

The density estimate for golden eagles is a key input into the Cochrane model and our estimate (0.036 golden eagles/km^2) was higher than the estimate used in Cochrane et al. (2015) (0.027 golden eagles/km^2), which was quantified using USFWS aerial survey data from the majority of the state of Wyoming (Nielson et al. 2014). The location of our study area in the southeast part of the state has some of the highest densities of golden eagles in Wyoming. Therefore, it seems reasonable that our eagle density estimate is higher than the state average.

The landscape within our study area allowed for excellent visibility for our road surveys and we were able to adequately spot golden eagles both in flight and at perches. We were only able to conduct road surveys on 1 occasion during 1 of the 2 hunting seasons we considered. Although using field data is preferable to other options, increasing the number of surveys throughout the hunting season, and in each year, would likely result in a more accurate and robust estimate of eagles exposed to lead from hunting. This could be an important improvement to future research efforts and a necessity as lead mitigation is formally implemented to offset eagle deaths.

Eagle take permits that have been issued to wind facilities in the past have covered 30 years and are reassessed every 5 years (USFWS 2016). When compensatory mitigation is required in this scenario, predicted fatalities are calculated for the first 5-year period and are designed to account for direct and indirect effects leading to eagle mortality. Thus, a facility that is expected to take 10 eagles over 30 years would need to mitigate for 2 eagles during the first 5 years of operation (1.67 eagles over 5 years × 1.2 replacement eagles required by USFWS

[2016]) assuming there are no additional indirect effects caused by reduction in reproductive output caused by a fatality. For example, the Two Rivers Wind Project in Carbon and Albany counties in Wyoming is predicted to take 22 golden eagles over the first 5 years of operation, or 4.4 golden eagles/year (Bureau of Land Management and USFWS 2022). Such levels of estimated take could theoretically be mitigated if we approximately doubled the efforts described herein.

Given the relatively high rate of response to our outreach, we chose not to make assumptions or employ statistical methods to estimate the participation or harvest rates of hunters who accepted non-lead ammunition but then subsequently did not take our post-hunting season survey. This means that if there was nonresponse bias in our data collection, it would have resulted in an underestimate of the positive impact of our program. Also, we did not make any assumptions regarding benefits to eagles by hunters who used non-lead ammunition we provided outside our study area or in subsequent years. Similarly, our calculations ignore the known increase in eagle density caused by an influx of migrant eagles in the later months of the hunting season. Together, these assumptions mean that our analysis may underestimate the true rate at which eagle fatalities were reduced by our program.

Another assumption of our approach is that all hunters who accepted non-lead ammunition from us would otherwise have hunted with lead ammunition. Non-lead ammunition is widely available to big game hunters in Wyoming and appears to be regularly used based on preliminary information obtained from our post hunt survey (Supporting Information). However, since it was outside the scope of our study to formally analyze the replacement component of our efforts to distribute non-lead ammunition, we could not estimate this metric with any certainty. In contrast to the assumptions above, violations of this assumption would mean that our analysis may overestimate the true rate at which eagle fatalities were reduced by our program. As such, if this model were used in a mitigation setting, it would be important to estimate the proportion of hunters that are already using non-lead ammunition and account for that in the design of the mitigative action. Alternatively, the USFWS may consider the benefit of issuing non-lead ammunition to any willing hunter regardless of previous or planned use to ensure the total relative benefit to eagles.

MANAGEMENT IMPLICATIONS

Our study provided empirical data as inputs to a theoretical lead abatement model developed for mitigating golden eagle fatalities in Wyoming. This effort suggests that the use of non-lead ammunition may be a successful tool in reducing modeled estimates of eagle mortality in Wyoming from lead exposure. Our study directly addresses substantial impediments to diversifying quantifiable mitigation actions for golden eagle fatalities. It therefore presents industry and the USFWS with a usable framework for implementation of compensatory mitigation for golden eagles that does not involve retrofitting power poles. For example, this effort could be highly relevant should the USFWS choose to formulate a resource equivalency analysis (REA) for non-lead ammunition as a form of compensatory mitigation that is similar to the REA that already exists for power pole retrofits (USFWS 2016*b*).

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

Samples from live animals were not used in this work. Therefore, institutional animal care and use committee and animal capture permits were not required (Sikes et al. 2019).

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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SUPPORTING INFORMATION

Additional supporting material may be found in the online version of this article at the publisher's website.

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