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Illegal killing of nongame wildlife and recreational shooting in conservation areas

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Abstract

Illegal killing of nongame wildlife is a global yet poorly documented problem. The prevalence and ecological consequences of illegal killing are often underestimated or completely unknown. We review the practice of legal recreational shooting and present data gathered from telemetry, surveys, and observations on its association with illegal killing of wildlife (birds and snakes) within conservation areas in Idaho, USA. In total, 33% of telemetered long-billed curlews (*Numenius americanus*) and 59% of other bird carcasses found with known cause of death (or 32% of total) were illegally shot. Analysis of spatial distributions of illegal and legal shooting is consistent with birds being shot illegally in the course of otherwise legal recreational shooting, but snakes being intentionally sought out and targeted elsewhere, in locations where they congregate. Preliminary public surveys indicate that most recreational shooters find abhorrent the practice of illegal killing of wildlife. Viewed through this lens, our data may imply only a small fraction of recreational shooters is responsible for this activity. This study highlights a poorly known conservation problem that could have broad implications for some species and populations of wildlife.

KEYWORDS

conservation areas, illegal killing, nongame wildlife, poaching, protected areas, recreational shooting

1 | INTRODUCTION

Harvest of wild animals occurs globally, takes many forms, and has important implications for conservation of biodiversity. This activity can be legal, regulated, sustainable, and compatible with biodiversity conservation (Rudolph & Riley, 2017). However, wildlife removal from natural systems may also have negative implications for conservation (Phelps, Biggs, & Webb, 2016). For example, illegal harvest for purposes of traditional medicine is a root cause of dramatic population declines for some ungulates (Theng, Glikman, & Milner-Gulland, 2018), big cats (Niraj, Sethi, Goyal, & Choudhary, 2019), and pangolins (Challender, Heinrich, Shepherd, & Katsis, 2020). Likewise, bushmeat hunting, which can be legal or illegal, influences population dynamics for many species of wildlife (Ripple et al., 2016). Similar processes occur in freshwater and marine systems, and unsustainable practices have led to local extirpation of target species (Pelicice et al., 2017; Di Minin et al., 2019). Predatory wildlife also are killed to protect livestock, causing population declines (Nyhus, 2016) and, potentially, trophic cascades or mesopredator release (Ritchie & Johnson, 2009). These actions have additional conservation significance, as they may lead to unintentional or intentional fatalities and collapse of nontarget scavenger populations (Ogada et al., 2016).

Within many countries, legal wildlife harvest occurs for many of the reasons noted above—medicine, trophy or food hunting, and predator control—but also for recreational purposes. For example, some nongame wildlife, particularly colonial rodents, are legally shot in large numbers for recreational purposes and their carcasses left in the field where they fall (McTee, Hiller, & Ramsey, 2019). There are poorly understood ecological consequences of this legal killing of wildlife for recreational, nonconsumptive purposes. For example, recreational shooting may result in behavioral changes or demographic consequences for targeted species (Vosburgh & Irby, 1998), and it also provides a food subsidy for scavengers (Golden, Warner, & Coffey, 2016; McTee et al., 2019) whose populations may reduce numbers of other species (Esque et al., 2010). Recreational shooting, in general, also can result in deposition of large quantities of lead on the landscape (Huxoll, 2012). Spent lead can percolate through vegetative communities (Selonen & Setälä, 2015) and into wildlife (Scheuhammer, Bond, Burgess, & Rodrigue, 2003) and scavengers (Knopper, Mineau, Scheuhammer, Bond, & McKinnon, 2006).

A secondary outcome associated with legal recreational killing of nongame wildlife is that other nontarget wildlife may be killed illegally (see Table 1 for definitions of terminology). Although illegal hunting of game species and its scope, causes, and consequences are sometimes the subject of study (Duffy, St John, Büscher, & Brockington, 2016), there is almost no knowledge of the role and conservation significance of illegal killing associated with recreational shooting (the one exception to this is the special case of shooting of birds at migratory bottlenecks; Sutton, 1928; Brochet et al., 2016). Such illegal killing may be so rare as to be demographically irrelevant, or it may be common enough to have population-level consequences. Without basic information on this problem, it is difficult to understand the drivers of the behavior, or to fully develop management actions and law enforcement strategies to mitigate for it.

TABLE 1 Definitions of terms and concepts related to illegal killing of nongame wildlife and its association with recreational shooting

Conservation area: A land area with some type of protected status; includes parks, natural areas and, in Idaho, USA, places named "conservation areas."
Distribution power line: A power line used to distribute electrical power from a transmission line to its end user; energized lines are frequently close enough together that a bird's wings can touch two lines at once, causing electrocution.
Illegal killing of wildlife: Killing of wildlife when in violation of law (state, federal, or other) or rule (species permitted to be hunted but may be illegally killed out of season or range). When accomplished by firearm, this becomes *illegal shooting of wildlife*.
Intensity of shooting: A score based on a modeled map predicting suitability for recreational shooting.
Legal recreational shooting: Shooting of a firearm in pursuit of recreation; targets are not intended for consumption and may be inanimate or animate. Only certain wildlife are permitted to be shot for recreation, and such shooting often occurs within a specified season and may require a permit.
Nongame wildlife: Wildlife species not typically harvested for human consumption (including fur or commercial purposes). *Game species* are those harvested for human consumption. These terms are defined in a variety of ways by different management authorities and authors.
Protected species: Those species protected by law or management rule, and for which killing is regulated. There are no regulations concerning numbers of *unprotected species* that may be killed.
Transmission power line: A power line used to transmit electrical power long distances; energized lines are usually too far apart to electrocute birds.
Snake hibernacula: A cave, rock pile, or other location where snakes congregate during winter and sometimes to birth young.

Here, we analyze evidence of illegal killing of non-game wildlife in association with high levels of legal recreational shooting on public land managed for conservation in southwestern Idaho. The wildlife that are illegally killed are nominally protected, either by statute (i.e., there is a state or federal law that protects them) or by rule (i.e., they are managed populations for which limited legal hunting is permitted at certain times and places). As a context for the illegal activity we document, first we provide background information on legal recreational shooting within the United States. Second, we illustrate the taxonomic scale of illegal killing with data on protected taxa shot within conservation areas in the state of Idaho. Third, we analyze spatial relationships between legal recreational shooting and illegal killing activity to evaluate support for the hypothesis of cause and effect relationships between the two. Finally, we use our review and analyses as a foundation to discuss potential motivators and broader consequences of illegal killing and we highlight knowledge gaps and potential next steps identified by our study.

2 | LEGAL RECREATIONAL SHOOTING IN THE UNITED STATES—A BRIEF REVIEW

Recreational shooting, including the shooting of wildlife, is a culturally important and legal recreational activity in many societies and countries (Lee & DeVore, 1968). In the United States, legal recreational shooting can take two forms. The first is target shooting of inanimate objects, either those fixed in place or projectiles (e.g., "clay pigeons"). Target shooting in the United States occurs legally on private and public (state or federally owned) lands, although some areas do have restrictions on shooting activity. The second form of legal recreational shooting involves killing of unprotected or managed nongame wildlife that are not consumed by humans and are usually left in the field where they fall. Commonly shot taxa include sciurids (prairie dogs, *Cynomys* spp.; ground squirrels, *Spermophilus* spp.; marmots, *Marmota* spp.), carnivores (coyotes, *Canis latrans*; badgers, *Taxidea taxus*), corvids (American crows, *Corvus brachyrhynchos*), and jackrabbits (*Lepus* spp.).

Ground squirrel shooting is heavily subscribed in the American West. In South Dakota, it is estimated that 1.5 million black-tailed prairie dogs (*Cynomys ludovicianus*) have been killed in a single year by licensed hunters (Huxoll, 2012). In one ~484 km^2 survey area of the southwestern Idaho region where we collected data for this study, a conservative estimate is that 152,750 Piute ground squirrels (*Urocitellus mollis*) may be shot during an 18-week season that extends from March to June (Pauli et al., 2019; Idaho Army National Guard, unpublished data). Shooting at these rates would annually remove ~9% of all ground squirrels in that area (Z. K. D., unpublished observations). Both the South Dakota and Idaho studies note the large quantities of lead ammunition deposited in the landscape, an estimated ~190 kg per year in the Idaho study area.

Shooting of unprotected wildlife is controlled by state agencies and, therefore, the laws regulating that activity vary by state. Similarly, the motivations for killing these wildlife vary by region and ecosystem; often shooting is primarily for recreation but also cast as a form of population control. In Idaho (where our studies occurred), a valid small game hunting license is required to shoot unlimited numbers of coyotes, jackrabbits, Piute ground squirrels, and crows (the latter are a managed population that can only be shot during an October–January season). Shooting of the seven other species of sciurids present in the state is not allowed (Idaho Department of Fish and Game, 2019). However, neighboring states have different regulations. In adjacent Wyoming, for example, prairie dogs are defined as nongame animals and coyotes, jackrabbits, raccoons (*Procyon lotor*), red foxes (*Vulpes vulpes*), porcupines (*Erethizon dorsatum*), and skunks (Family Mephitidae) are classified as predators. For all these species, there are no bag limits and a hunting license is not required to shoot them (Wyoming Game and Fish Department, 2019). Legal recreational shooting of nongame wildlife may be associated with preventing damage to agriculture, or with sporting events such as predator hunts or coyote calling contests (http://worldchampionshipcoyotecallingcontest.com/), crow shooting competitions (https://www.newyorkupstate.com/outdoors/2019/03/upstate-ny-rod-and-gun-club-holding-6th-annual-crow-hunt.html and https://www.outdoornews.com/2018/03/16/crow-shoot-competition-fire-vermont/), and, in at least 10 states, rattlesnake roundups (http://www.rattlesnakeroundup.net/; Knight & Gutzwiller, 1995).

3 | METHODS

3.1 | Study area

We collected data on illegal killing of nongame wildlife in two conservation areas in southwestern Idaho, the Morley Nelson Snake River Birds of Prey National Conservation Area (NCA) and the Long-billed Curlew Habitat Area of Critical Environmental Concern (ACEC; Figure 1; see Appendix, Study Area, for extended details on these areas). The majority of land cover in both was originally shrub-steppe dominated by big sagebrush (*Artemisia tridentata*; Knick & Rotenberry, 2000).

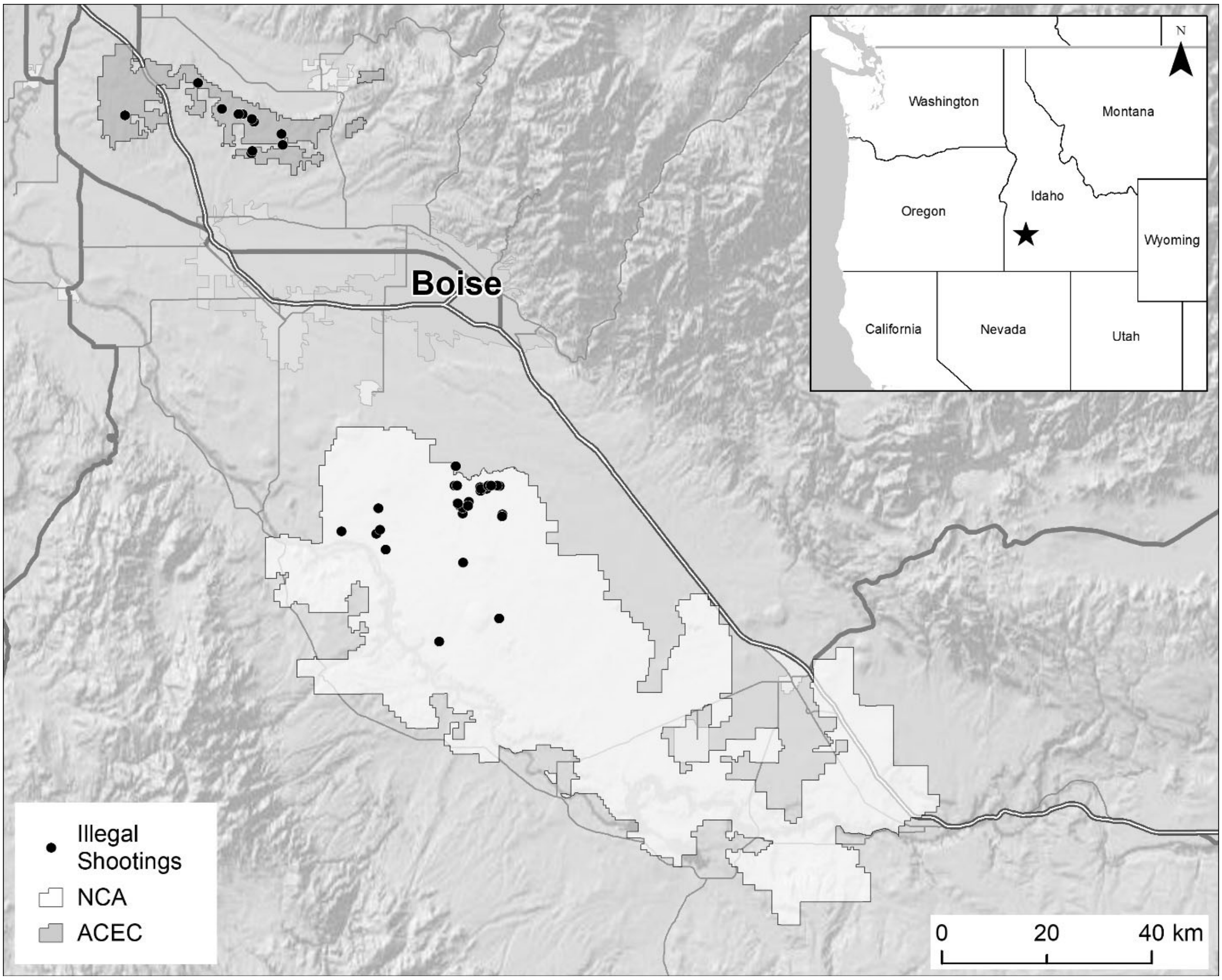

FIGURE 1 Location of the Long-billed Curlew Habitat Area of Critical Environmental Concern (ACEC, shaded, in the northwest of the map) and the Morley Nelson Snake River Birds of Prey National Conservation Area (NCA; lightened, south of the city of Boise) in southwestern Idaho. Black dots are the locations at which we found illegally shot birds. Inset shows the location in the northwestern United States

However, increased fire frequency has converted much of the landscape to grasslands dominated by native perennial grasses, especially *Poa secunda*, and non-native annual grasses and forbs such as *Bromus tectorum*, *Sisymbrium altissimum*, and *Salsola tragus* (Pilliod, Welty, & Arkle, 2017; Yensen, Quinney, Johnson, Timmerman, & Steenhof, 1992). The high density of ground squirrels, the proximity to urban areas, and the open-access management of the two areas attract large numbers of legal recreational shooters. On weekends from February to July, many hundreds of shooters are distributed along only a few kilometers of roadway in the NCA (Pauli et al., 2019; MCA & IDARNG, unpublished data).

3.2 | Field data collection

We used three sources of data in this study, all collected in the NCA and ACEC. Two data sets were collected in the course of research into the local decline of long-billed curlews (*Numenius americanus*) and into causes of death of large birds of many species along power lines. We added to this anecdotal evidence of shooting of wildlife that was collected in the course of other field activities. For example, birds are commonly found dead near roadways, and reptiles have been monitored on the NCA since 1975 (Diller, 1982). The killing of these wildlife was, in nearly all cases, in violation of state or federal law, or both (some of the snake killing we documented may have been legal if done in a particular manner; Idaho Statute 36 governs taking of wildlife within the state, the Migratory Bird Treaty Act and the Bald and Golden Eagle Protection Act provide federal protections for birds).

3.2.1 | Field data collection—Curlews

Long-billed curlews are North America's largest shorebird and, through mutual associations with grassland habitats (Dugger & Dugger, 2002), co-occur with legally shot species including ground squirrels and prairie dogs. Curlews nest on the ground in open, generally grassy habitats throughout much of the Intermountain West and Great Plains of the United States and Canada (Dugger & Dugger, 2002; Fellows & Jones, 2009). Because of the extensive loss and degradation of their nesting habitat, curlews of all types are recognized as a taxonomic group of conservation concern globally (Pearce-Higgins et al., 2017), continentally (North American Bird Conservation Initiative (NABCI), 2016), and regionally (Idaho Department of Fish and Game, 2017; U.S. Bureau of Land Management, 2014; COSEWIC, 2011; for additional details on this species, see Appendix, Long-billed Curlew).

Monitoring of curlews at the ACEC (from 2009 to 2019) and the NCA (2016 to 2019) that resulted in data collection for this study has included nest searches and associated trapping and telemetry of adult birds. We found curlew nests via distant observation of pair activity (i.e., watching when parents switch nest tending duties), with locations later confirmed by a single visit to the exact nest site. To capture birds, we gently dropped a mist net over adult curlews incubating on the nest (Page et al., 2014). We banded captured birds, gave them a green leg flag with white letters, and outfitted each one with a 9.5 g solar satellite telemetry device (Microwave Telemetry, Inc., Columbia, MD) attached with a leg-loop harness of Teflon ribbon (Page et al., 2014). We used a 29-hr duty cycle for the telemetry devices, such that they collected satellite data for 5 hr and were turned off for the following 24 hr. Data were monitored approximately daily and, when telemetry data suggested that the transmitter had stopped moving (i.e., the bird had died or the transmitter had fallen from the bird), we recovered the transmitter and, when present, the bird carcass, from the field. In all cases, cause of death was determined by necropsy at the Idaho Department of Fish and Game Wildlife Health Laboratory or suspected based on bullet holes, location of the carcass, or lack of evidence of predation.

3.2.2 | Field data collection—Birds on power lines

Many species of raptors and other large birds in the NCA perch in prominent locations that make them highly visible in the shrub-steppe landscape (see Appendix, Avian Assemblage, for details on the avian assemblage at the NCA). Especially relevant perches are on the high voltage electrical transmission lines and lower voltage distribution lines. Distribution lines have wires spaced closer together and therefore pose a greater risk of electrocution to large birds than do transmission lines (Avian Power Line Interaction Committee (APLIC), 2006). Roads along both types of lines provide access that can bring people close to perched or nesting animals.

To understand causes of death of large birds in the NCA, we conducted walking surveys for avian carcasses under power lines every 2 weeks between March 5 and October 18, 2019. Our surveys covered 8 sections of transmission lines, totaling 37.6 km in length and with 263 towers or structures, and 8 sections of distribution lines, totaling 17.4 km and with 203 structures (Figure 2). Survey sections were selected randomly from the many distribution lines, electrified or not, within or adjacent to the NCA. As there are only two major transmission lines crossing the NCA, we randomly selected for survey segments along those two lines. Searchers walked along the power line and around each power pole or structure, generally within a 10-m radius. Carcasses were identified to species, photos taken and locations collected on a camera- and GPS-enabled handheld Android field data collection device (CP3, Juniper Systems, Inc., Logan, UT) running custom designed forms within Survey123 and Collector for ArcGIS (Esri, Redlands, CA). We assessed cause of death first in the field based on gross characteristics (e.g., burn marks, bullet holes), and again during a professional necropsy.

3.2.3 | Field data collection—Snakes

We also recorded anthropogenically caused fatalities of wildlife when detected incidentally along roads and in other locations in the NCA and ACEC. Of particular note in this case were the large birds noted above and two snake species, the Great Basin rattlesnake (*Crotalus oreganus lutosus*) and Great Basin gopher snake (*Pituophis catenifer deserticola*), that have been the focus of several studies on the NCA (Diller, 1982; Cossel, 2003; Parker & Pilliod, unpublished data; also see Appendix, Snakes, for details on snakes).

3.3 | Data analysis

We developed and tested hypotheses about the cause and effect relationships between legal recreational shooting and illegal killing of nongame wildlife. We reasoned that spatial association of recreational shooting and illegal killing of nongame wildlife would be consistent with the hypothesis that some people were doing both at the same time. Lack of spatial association would suggest that the illegal activity was done by different people or by the same people at different times. Because most data for this

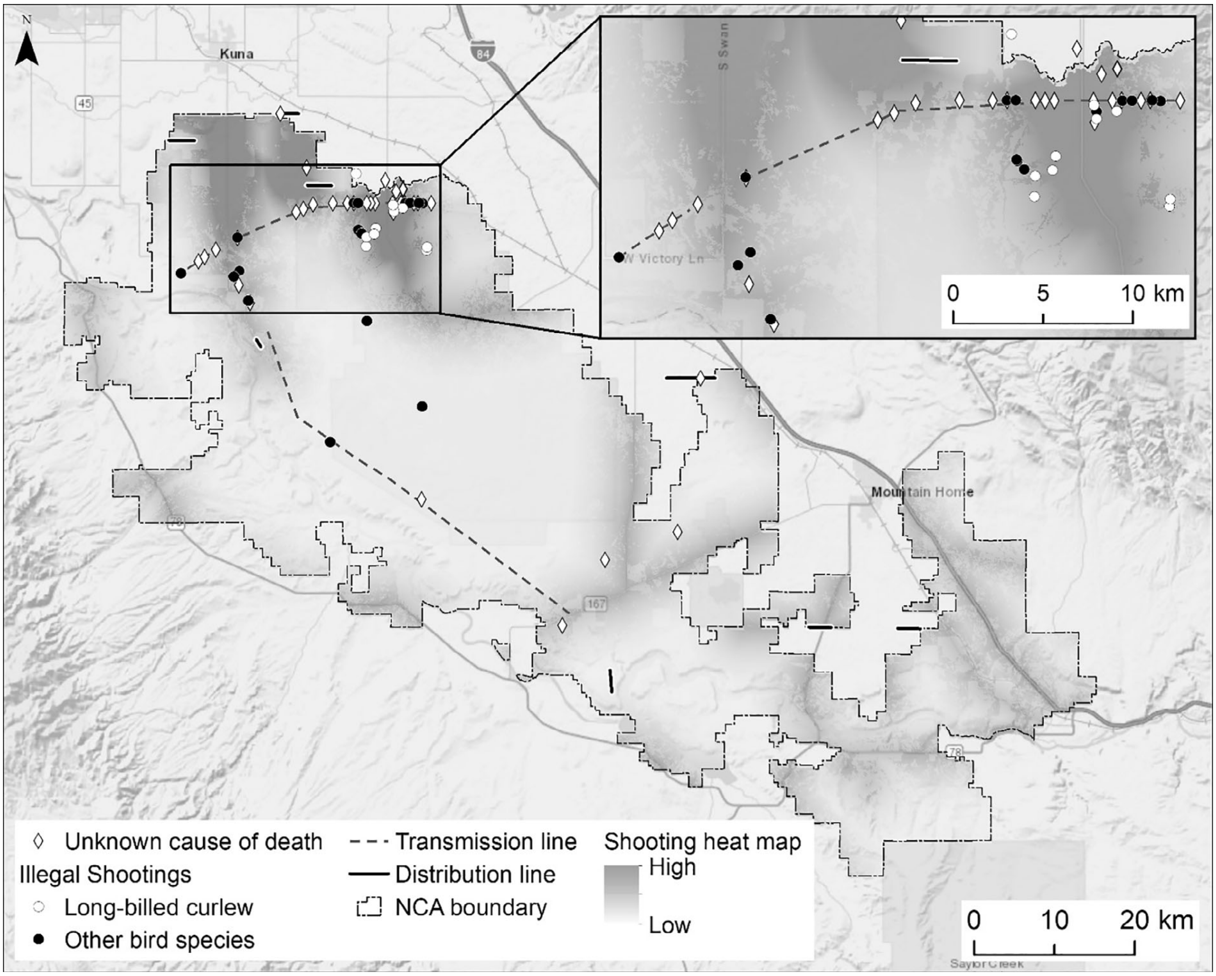

FIGURE 2 Association between legal recreational shooting and locations of illegally shot birds and birds that died of unknown causes within the Morley Nelson Snake River Birds of Prey National Conservation Area (NCA) in southwestern Idaho. The grayscale gradient in the background describes the modeled intensity of legal recreational shooting activity (from Pauli et al., 2019). Circles show locations of illegally shot curlews (open circles) and all other birds (filled circles). Open diamonds show locations of birds (curlews and others) that died of unknown causes. Also shown are transmission (dotted lines) and distribution (solid lines) power lines along which we conducted surveys for bird carcasses

project were collected during the spring and summer, we had little opportunity to evaluate either temporal patterns in the data or associations with seasonal fluctuations in shooting or hunting behavior.

A recent study used presence-only species distribution modeling with MaxEnt software to create a continuous modeled surface (a "heat map") of predicted intensity of recreational shooting within the NCA (Pauli et al., 2019). The response variable in the model was locations of shooters as determined by 48 km of transects in the northern part of the NCA. The model included four predictors for recreational shooting locations: distance of a location from the nearest major urban center, distance to the nearest major road, land cover type, and elevation. The first two were negatively correlated to predicted intensity of recreational shooting (i.e., recreational shooting was predicted to occur closer to urban areas and to roads) and the last two made only minor contributions to the final model (AUC = 0.74; for more details on model fit see Pauli et al., 2019).

We identified on that heat map the locations of all carcasses of curlews, other protected or managed birds, and snakes that we found dead during fieldwork. We then used a GIS (ArcMap 10.6, Esri) to assign to each carcass the modeled shooting intensity score (rescaled from the original to a range of 0–1) at the location where it was found. Thus, a carcass found at a location with a high intensity of recreational shooting would receive a score closer to one, and a carcass found at a site with low intensity of recreational shooting would receive a score closer to zero. To test for other potential confounding anthropogenic factors, we also evaluated distance from each carcass to improved roads (those with aggregate or solid surfaces) and to transmission power lines within the NCA. Subsequently, we evaluated heat map scores for power lines surveyed in the NCA to confirm that they were sampled across the distribution of potential heat map scores.

We used a two-sample, two-sided Kolmogorov–Smirnov test to evaluate if the distribution describing the shooting intensity scores of wildlife carcasses could be the result of random sampling from the global distribution describing the shooting intensity scores within the entire NCA. Finally, we used a Wilcoxon Rank Sum Test to evaluate if distance from carcass locations to roads and to transmission power lines differed from that expected from random. To build this comparison dataset, we randomly generated two points, sampled from across the entire study area, for each protected bird or snake carcass found, and, for each random point, we estimated a distance to road and to transmission power lines (i.e., for each analysis we had two random locations to compare to each carcass location; this provided good coverage of the entire study area). We ran statistical analyses in R using the base R package (R Core Team, 2018).

4 | RESULTS

4.1 | Evidence of illegal killing of nongame wildlife

In the course of this work, we put telemetry devices on 11 adult curlews in the ACEC and another 10 in the NCA. Of these 21 telemetered birds, 33% ($n = 7$) were shot illegally (Figure 2, Figure 3a). This includes all four birds marked in a small area of the NCA that our MaxEnt model identified as having a high intensity of recreational shooting (heat map scores for these four were 0.17–0.29), none of the six marked in areas of low intensity of shooting in the NCA, and three of 11 birds marked in the ACEC. Shootings often occurred during the spring months when curlews perform flight displays and aggressively defend their young (April–June). In addition, nine carcasses of unmarked curlews were found between 2008 and 2016 in the ACEC, and eight were found between 2017 and 2019 in the NCA (heat map scores of those eight were 0.20–0.85; Figure 2).

We found 30 avian carcasses during power line surveys and 97 other avian carcasses incidentally (Appendix Table S1). Almost half of these 127 were found incidentally in June, in a single group that included 55 rock pigeons (*Columba livia*), which can be legally shot, and 6 mourning doves (*Zenaida macroura*), which are protected and cannot be legally shot except during a September–October hunting season. The majority (84%) of birds found during power line surveys were under transmission lines. Of the 71 birds of protected species found dead, the greatest number (29, or 41%) were common ravens (*Corvus corax*); two others were curlews as reported above. A cause of death was determined for 39 of the protected birds (Table S1). Of these, 59% ($n = 23$) had been shot illegally; the others were electrocuted or died of blunt force trauma (usually collision with vehicles, power lines, or other structures).

Finally, between 2013 and 2019, biologists incidentally documented 11 events in which 35 snakes were killed at 5 locations within the NCA (Figure 3b; Appendix; Table S2; locations not shown to protect these sites from future persecution). All but three events were associated with casings of spent ammunition from small-bore firearms (usually .22 caliber cartridges).

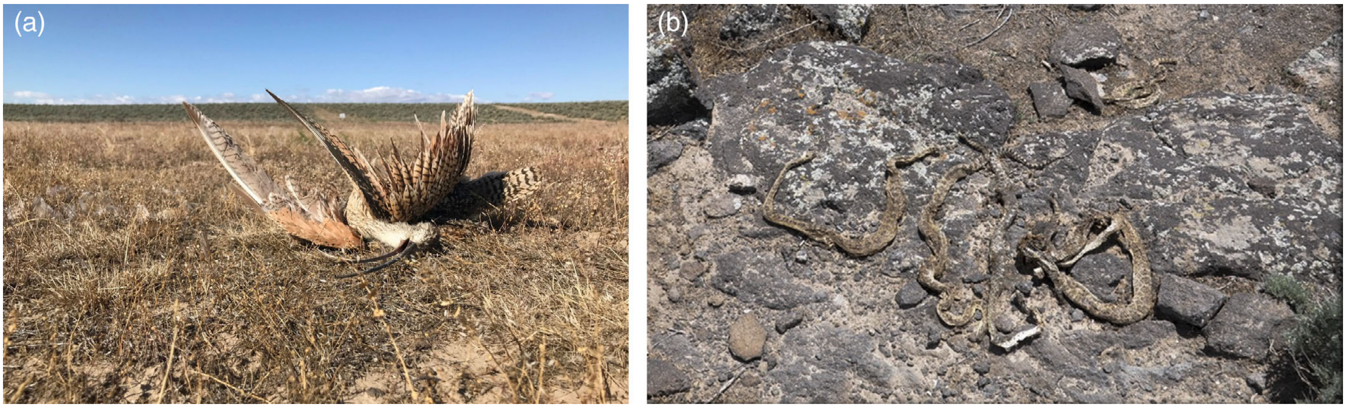

FIGURE 3 Illegally killed (a) curlew (credit: Stephanie Coates); and (b) rattlesnakes (credit: Kevin Warner/IDARNG) within the Morley Nelson Snake River Birds of Prey National Conservation Area in southwestern Idaho. Death of birds, but not of snakes, was associated with recreational shooting. See text for details

4.2 | Association between legal shooting and illegal killing

Heat map scores of the locations of the 26 birds (10 curlews, 16 other birds) known to be illegally shot within the NCA were not randomly sampled from potential heat map scores (Table 2; Figure 4a,b; other illegally shot birds were found outside the boundaries of the heat map and so could not be assigned scores). Instead, their locations were strongly associated with areas of high intensity of recreational shooting (mean heat map score, $\bar{x}_{\text{illegally shot curlews + others}} = 0.29$; $D_n = 0.76$, $p <$ a; Table 2). The locations of the 28 birds that died of unknown causes also were strongly associated with recreational shooting ($\bar{x} = 0.26$; $D_n = 0.65$, $p < 0.001$; Table 2, Figure 4a,c). Both transmission and distribution lines tend to occur closer to population centers, and the lines we sampled included the entire range of heat map scores but average scores along power lines were above the overall average for the heat map ($\bar{x}_{\text{transmission}} = 0.13$, range of mean section scores: 0.00–0.87; $\bar{x}_{\text{distribution}} = 0.11$, range of mean section scores: 0.00–0.42; $\bar{x}_{\text{heat map}} = 0.06$, range: 0–1). Accordingly, the few birds that died of electrocution also tended to be associated with recreational shooting areas. In contrast, birds that died of trauma and locations at which snakes were killed were not associated with areas of recreational shooting (Table 2).

Finally, most causes of death of animals were not randomly distributed relative to anthropogenic infrastructure. Specifically, locations of carcasses of most types were closer to roads and transmission lines than expected ($p \leq 0.033$ for distance to roads for illegally shot birds, electrocutions, unknown causes of death, and snakes; $p \leq 0.001$ for distance to transmission lines for illegally shot birds other than curlews, trauma, and unknown causes of death; Table 2, Table S3). The exceptions to this pattern were for a few of the categories with very small sample sizes ($p > 0.05$ for distance to roads for trauma, and for distance to power lines for illegally shot curlews, electrocutions, and snakes).

TABLE 2 Mean ($\bar{x}$) and range of shooting intensity scores at locations where we found illegally shot birds (long-billed curlew "Curlew," and all other birds), birds of all species ("Birds") that died of trauma or electrocution, birds for which cause of death was unknown, and dead snakes (many of which were illegally shot). Shooting intensity scores were calculated from a continuous modeled surface of intensity of recreational shooting within the Morley Nelson Snake River Birds of Prey National Conservation Area (NCA; Pauli et al., 2019), rescaled to a range of 0–1. Also shown are data from the entire modeled map ("heat map") within the NCA, and distances from carcasses to improved roads and transmission power lines. Test statistics (D_n) and p-values are for a Kolmogorov–Smirnov test to evaluate if the distribution describing the shooting intensity scores for each category of dead birds and snakes could be the result of random sampling from the distribution describing the shooting intensity scores of the entire heat map of the NCA (Figure 4 shows the distribution of heat map scores for illegally shot birds and that for the entire heat map). Asterisks indicate a statistically significant difference between distances to roads and power lines from random points and from locations of animal carcasses (see Table S3 for details and test statistics)

							Distance (m) to			
			Heat map score				Improved roads		Transmission power lines	
Cause of death	Taxa	n	$\bar{x}$	Range	D_n	p	$\bar{x}$	Range	$\bar{x}$	Range
Illegally shot	Curlew	10[a]	0.44	0.16–0.85	0.93	<0.001	375*	32–991	2,175	185–4,264
	Other birds	16[b]	0.19	0.00–0.43	0.66	<0.001	750*	11–2,299	1,338*	2–8,967
Trauma	Birds	6[b]	0.11	0.00–0.26	0.48	0.128	789	1–2,840	635*	4–3,061
Electrocution	Birds	4[b]	0.25	0.11–0.52	0.85	0.006	422*	2–1,663	1,720	16–4,120
Unknown	Curlew	1[a]	0.26	—	—	—	810	—	1,066	—
	Other birds	27	0.26	0.00–0.77	0.65	<0.001	809*	1–3,105	201*	0–3,399
Shot/trauma	Snake	5[c]	0.08	0.00–0.28	0.21	0.983	599*	3–2,213	5,087	2,167–8,425
Heat map	*Entire NCA*	*2,700,406*	*0.06*	*0.00–1.00*	—	—	—	—	—	—

[a]The 10 + 1 = 11 curlews here include 2 unmarked animals collected during surveys (1 shot, 1 unknown) and reported in Table S1, 6 others found incidentally and shot, and 3 telemetered animals recovered after being shot. One additional marked curlew was recovered after being shot but is not included here because it was found just outside the NCA.
[b]Two of the birds that died of trauma and four of the electrocuted birds were found just outside the boundaries of the heat map and thus could not be assigned a heat map score. The same is true for the six mourning doves found dumped within the NCA (i.e., we assume they were shot elsewhere and left inside the NCA, thus a heat map score is not appropriate).
[c]The 35 dead snakes documented in Table S2 were found at the 5 hibernacula whose locations are analyzed here.

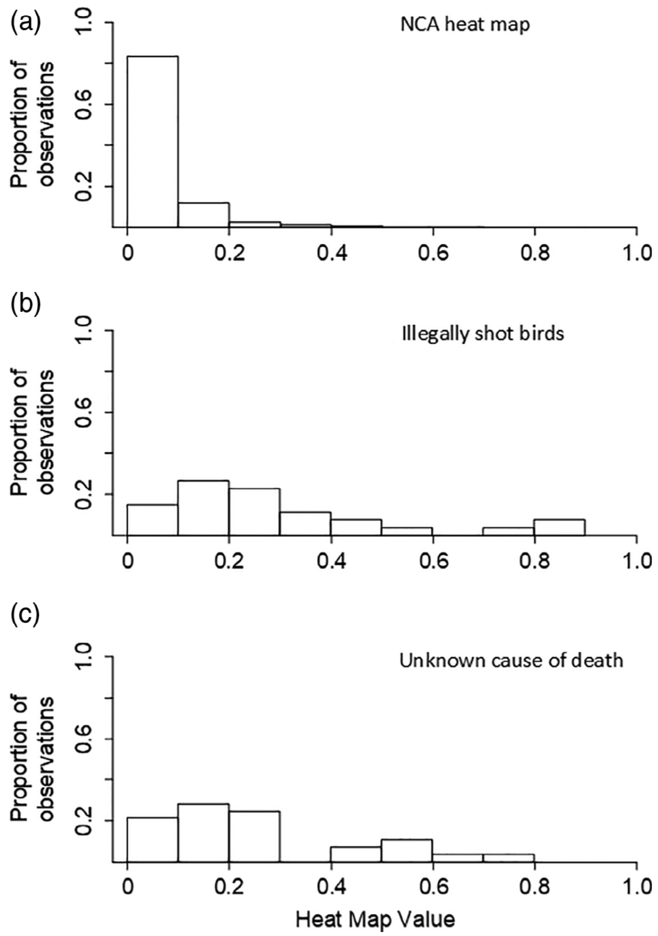

FIGURE 4 Histograms showing the distributions of heat map scores for (a) all locations within a heat map (Pauli et al., 2019) describing shooting intensity within the Morley Nelson Snake River Birds of Prey National Conservation Area (NCA) in southwestern Idaho; (b) locations of illegally shot birds found within the NCA; and (c) locations of birds whose cause of death is not known that were found within the NCA. A Kolmogorov–Smirnov test showed that the distributions in (b) or (c) were not the result of random sampling from the distribution in (a); test results are in Table 2 and the main text

5 | DISCUSSION

Although not all the data we present here were collected in the course of research into causes of mortality, they paint a compelling picture of illegal killing of nongame wildlife that was, in the case of birds, strongly associated with areas where legal recreational shooting is prevalent. The spatial pattern of this activity, with high intensity of occurrence near areas of high human population density, near roads, along power lines, and within conservation areas, provides key information that can form the foundation of subsequent resource management and conservation planning.

5.1 | Factors associated with illegal killing of wildlife

The NCA and the ACEC were established to aid in conservation of locally robust populations of raptors and curlews, respectively. It is, therefore, ironic that these species are among those we documented as illegally shot. Although curlews elsewhere are not thought to be targeted by shooters, raptors, globally, regularly are shot (Olson, 1999; Russell & Franson, 2014), in part because they are viewed as threats to livestock or game (Redpath et al., 2013). Snakes, and particularly rattlesnakes, also are killed because of the threat they are perceived to present to livestock and humans (Sasaki, Place, & Gaylor, 2008).

The association between heat map scores for legal recreational shooting and illegal killing, and the lack of similar association for snakes and for birds killed by blunt force trauma, provides important and generalizable insight into the factors involved with illegal killing of wildlife. The linkage between legal recreational shooting and illegally shot birds is consistent with the illegal activity being opportunistic, rather than targeted (i.e., illegal shooters do not necessarily seek out and shoot protected species, instead they opportunistically or accidentally shoot targets that appear in their viewshed). It is also possible that illegal shooters are different people than recreational shooters who specifically seek out species that are not legal to hunt, and that they do so closer to the urban areas from where they come. However, this explanation seems unlikely since those who knowingly engage in illegal activity probably would not choose to do so in areas with the highest densities of legal recreationists. In contrast, the weak association between the legal recreational shooting and the illegal killing of snakes is consistent with the opposite pattern (i.e., shooters seek out places where snakes congregate, such as hibernacula, specifically to kill them; those places are in areas of low to moderate recreational shooting intensity).

The association of the deaths from electrocution with intensity of recreational shooting was unexpected but, in hindsight, logical. Most recreational shooting at the NCA occurs in the northwest part of the conservation area, a region that contains the most ground squirrels but that also is closer to urban areas. As such, it contains a higher density of improved roads and distribution power lines. Because the energized wires of distribution lines are close together, they present relatively higher risk of electrocution to birds than do transmission lines. This infrastructure creates anthropogenic threats, in this case electrocution, that is more common in areas with heavy human use. This observation is supported by the nonrandom distribution of all fatalities relative to anthropogenic infrastructure within the NCA. Furthermore, although this area is a hotspot of raptor density, it is not the only such hotspot within the NCA (Watson, Atkinson, Steenhof, & Rotenberry, 1996), and neither electrocution rates nor shooting were similarly high in other areas of high raptor density.

It is unclear whether the conservation status of these landscapes acts to drive or mitigate the illegal activity we observed. Neither the NCA nor the ACEC are clearly demarcated, there are few fences or barriers delineating their boundaries, and law enforcement resources are sparse. As such, the conservation status of these areas rarely is recognized by recreationists (MCA, unpublished observations), and likely is not influential in motivating or assuaging this illegal activity. Hunting of wildlife for food or trophies is widespread in protected areas worldwide (Benítez-López et al., 2017), and this study suggests that illegal shooting associated with recreation in conservation areas also likely occurs more than is commonly recognized.

5.2 | Broader consequences of illegal killing of nongame wildlife

Illegal killing of nongame wildlife has conservation relevance not only because it is unlawful but also because it can have consequences that extend past the death of an individual animal. Such consequences are difficult to assess in this study because our data either were not collected in a study of fatalities (in the case of curlews and snakes) or were collected in a study designed to document cause of death, rather than the frequency with which different causes of death occur (in the case of power line surveys).

Despite these challenges, we can draw inference from our work that could be used to inform conservation strategies in general. Comparisons of data from recent and historical surveys for curlews in southwestern Idaho show severe population declines of >90%, from 2,000+ individuals in the late 1970s (Jenni, Redmond, & Bicak, 1981) to <200 in 2014 (Pollock, Miller, & Carlisle, 2014). This decline is ongoing through 2019 (Coates, Hayes, Clapsadle, Dougill, & Carlisle, 2019), and contrasts with a more stable range-wide population (Sauer et al., 2017). Illegal shooting of curlews has been a long-standing practice at the ACEC, with nine reported shot from 1977 to 1979 (Jenni et al., 1981). The ≥33% rate of shooting mortality we observed among 21 tracked adult curlews suggests a potential role for illegal shooting in the dramatic long-term declines observed for the local population of this long-lived and slowly reproducing species.

In the case of birds found dead along power lines, the locations of the birds that died of unknown causes provide a clue as to their true cause of death. The spatial distribution of these unknown deaths was strongly associated with recreational shooting and often with transmission power lines along which electrocution is extremely unlikely, implying that they also may have died of gunshot. This pattern has broader implications because it suggests that illegal shooting is more common than might be inferred simply from the birds with a known cause of death (see Treves, Artelle, Darimont, and Parsons (2017) for a similar perspective from different taxa).

6 | CONCLUSIONS

Recent and preliminary interviews with recreational shooters ($n = 28$ people) at the NCA suggest that all were opposed to, and most find abhorrent, the practice of shooting nontarget species (MCA, unpublished data). If these are representative viewpoints, our work implies that much of the illegal killing in these conservation areas may possibly result from the actions, either purposeful, unintentional, or even stemming from ignorance, of a few individuals. If correct, this observation can help managers worldwide to frame policy approaches to confront this problem. In this case, the spatial correlates of illegal killing of birds (in areas of frequent recreational shooting) and of snakes (especially at hibernacula) that we identify could be used to target management, outreach, and enforcement activities.

There is good evidence that illegal shooting of wildlife is widespread, and likely relevant to wildlife, beyond southwestern Idaho. For example, the one published study to document large numbers of illegally shot birds along power lines was based in Montana (Olson, 1999). In southeastern Oregon, just across the border from our study region, a large number of birds found along power lines are known to be illegally shot rather than electrocuted, as was once assumed (Idaho Power Company, unpublished observations). Similarly, illegal persecution, often shooting, also is an important cause of death of golden eagles (*Aquila chrysaetos*) in North America and Europe (U.S. Fish and Wildlife Service, 2016; Whitfield & Fielding, 2017), and bald eagles (*Haliaeetus leucocephalus*) in Michigan (Simon et al., 2020). Finally, the decline of rattlesnake populations in several states is well documented and associated with heavy persecution (Parker & Brown, 1973; Warwick, Steedman, & Holford, 1991).

This study is a surface-level evaluation of a conservation problem whose depth is poorly known and likely underappreciated. That said, this work can provide a starting point for future studies of this problem.

Important research goals, therefore, are to design and implement research in areas of recreational shooting worldwide to estimate the species and numbers of wildlife killed illegally and the demographic consequences of this activity. That information could be part of a foundation for development of future management policies and conservation actions.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Jay D. Carlisle and **Todd E. Katzner** conceived of this study. **Jay D. Carlisle**, **Heather M. Hayes**, and **Stephanie E. Coates** designed and implemented the curlew studies and wrote the text on those studies. **David S. Pilliod**, **Kristina J. Parker**, **Kevin S. Warner**, and **Zoe K. Duran** collected the snake data and wrote the text on those studies. **Eve C. Thomason**, **Sandra M. Amdor**, **Steven E. Alsup**, **Sharon A. Poessel**, **Todd E. Katzner**, and **James R. Belthoff** designed and implemented the power line surveys and wrote the text on those studies. **Julie A. Heath** and **Benjamin P. Pauli** created the shooting heat map. **Zoe K. Duran** and **Madeline C. Aberg** collected survey data on ground squirrels and shooters. **Patricia A. Ortiz** managed data and avian carcasses for the power line studies. **Sharon A. Poessel**, **Tricia A. Miller**, and **Eve C. Thomason** made maps and **Sharon A. Poessel** led data analysis and made Figure 4. **Todd E. Katzner** led writing and all authors contributed to revisions.

DATA AVAILABILITY STATEMENT

All data for this paper are included in the manuscript or available at Boise State University ScholarWorks—https://scholarworks.boisestate.edu/.

ETHICS STATEMENTS

Capture of live animals (curlews) was performed under US Geological Survey Bird Banding Lab permit #22929, Idaho Fish and Game permit #990121 and Boise State University Animal Care and Use Protocols #AC14-008 and AC17-005. Salvage activities were conducted under Idaho Fish and Game permit #110728 and U.S. Fish and Wildlife Service Scientific Collecting Permit #MB72348.

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REFERENCES

Avian Power Line Interaction Committee (APLIC). (2006). *Suggested practices for avian protection on power lines: The state of the art in 2006*. Washington, DC: Edison Electric Institute, APLIC and the California Energy Commission.

Benítez-López, A., Alkemade, R., Schipper, A. M., Ingram, D. J., Verweij, P. A., Eikelboom, J. A. J., & Huijbregts, M. A. J. (2017). The impact of hunting on tropical mammal and bird populations. *Science*, *356*(6334), 180–183.

Brochet, A. L., van den Bossche, W., Jbour, S., Ndang'ang'a, P. K., Jones, V. R., Abdou, W. A. L. I., … Barbara, N. (2016). Preliminary assessment of the scope and scale of illegal killing and taking of birds in the Mediterranean. *Bird Conservation International*, *26*(1), 1–28.

Brown, W. S., & Parker, W. S. (1982). Niche dimensions and resource partitioning in a Great Basin desert snake community. In N. J. Scott (Ed.), *Herpetological communities. Wildlife Research Report 13* (pp. 59–81). Washington, DC: U.S. Fish and Wildlife Service.

Challender, D. W., Heinrich, S., Shepherd, C. R., & Katsis, L. K. (2020). International trade and trafficking in pangolins, 1900–2019. In D. W. S. Challender, H. C. Nash, & C. Waterman (Eds.), *Pangolins: Science, society and conservation* (pp. 259–276). London, England: Academic Press.

Clark, R. W., Brown, W. S., Stechert, R., & Greene, H. W. (2012). Cryptic sociality in rattlesnakes (*Crotalus horridus*) detected by kinship analysis. *Biology Letters*, *8*(4), 523–525.

Coates, S. E., Hayes, H. M. Clapsadle, J. L., Dougill, S. J., & Carlisle, J. D. (2019). Intermountain Bird Observatory Long-billed Curlew Research and Community Education: 2019 Status Report. Boise State University, Boise, ID.

Coates, S. E., Wright, B. W., & Carlisle, J. D. (2019). Long-billed curlew nest site selection and success in the Intermountain West. *The Journal of Wildlife Management*, *83*(5), 1197–1213.

COSEWIC (2011). COSEWIC status appraisal summary on the long-billed curlew *Numenius americanus* in Canada. In *Committee on the status of endangered wildlife in Canada*. Ottawa, Canada: Canadian Wildlife Service.

Cossel, J. O. (2003). *Changes in reptile populations in the Snake River Birds of Prey Area, Idaho, between 1978–79 and 1997–98: The effects of weather, habitat, and wildfire*. (PhD dissertation). Idaho State University, Pocatello, ID.

di Minin, E., Brooks, T. M., Toivonen, T., Butchart, S. H., Heikinheimo, V., Watson, J. E., … Moilanen, A. (2019). Identifying global centers of unsustainable commercial harvesting of species. *Science Advances*, *5*(4), eaau2879.

Diller, L. V. (1982). Ecology of Reptiles in the Snake River Birds of Prey Area. Final Report, 1975–1979 Snake River Birds of Prey Research Project. Retrieved from https://scholarworks.boisestate.edu/bop/Bibliography/Bibliography/92

Duffy, R., St John, F. A., Büscher, B., & Brockington, D. (2016). Toward a new understanding of the links between poverty and illegal wildlife hunting. *Conservation Biology*, *30*(1), 14–22.

Dugger, B. D., & Dugger, K. M. (2002). Long-billed curlew (*Numenius americanus*). In A. F. Poole & F. B. Gill (Eds.), *The birds of North America, v2.0*. Ithaca, NY: Cornell Lab of Ornithology.

Esque, T. C., Nussear, K. E., Drake, K. K., Walde, A. D., Berry, K. H., Averill-Murray, R. C., … Heaton, J. S. (2010). Effects of subsidized predators, resource variability, and human population density on desert tortoise populations in the Mojave Desert, USA. *Endangered Species Research*, *12*(2), 167–177.

Fellows, S. D., & Jones, S. L. (2009). Status assessment and conservation action plan for the long-billed curlew (*Numenius americanus*). U.S. Department of the Interior, Fish and Wildlife Service, Biological Technical Publication, USFWS, Region 6, Nongame Migratory Bird Coordinator's Office, Denver, CO.

Glaudas, X., Farrell, T. M., & May, P. G. (2005). Defensive behavior of free-ranging pygmy rattlesnakes (*Sistrurus miliarius*). *Copeia*, *2005*(1), 196–200.

Golden, N. H., Warner, S. E., & Coffey, M. J. (2016). A review and assessment of spent lead ammunition and its exposure and effects to scavenging birds in the United States. In W. de Voogt (Ed.), *Reviews of environmental contamination and toxicology volume 237* (pp. 123–191). Cham, Switzerland: Springer.

Hamilton, B. T., & Nowak, E. M. (2009). Relationships between insolation and rattlesnake hibernacula. *Western North American Naturalist*, *69*(3), 319–328.

Hayes, W. K., Herbert, S. S., Rehling, G. C., & Gennaro, J. F. (2002). Factors that influence venom expenditure in viperids and other snake species during predatory and defensive contexts. In G. W. Shuett, M. Höggren, M. E. Douglas, & H. W. Greene (Eds.), *Biology of the vipers* (pp. 207–233). Eagle Mountain, UT: Eagle Mountain Pub.

Heath, J. A., & Kochert, M. N. (2016). Golden Eagle dietary shifts in response to habitat alteration and consequences for eagle productivity in the Morley Nelson Snake River Birds of Prey National Conservation Area. Cooperator Final Report to the U. S. Fish and Wildlife Service. Boise State University, Raptor Research Center, Boise, ID.

Holding, M. L., Biardi, J. E., & Gibbs, H. L. (2016). Coevolution of venom function and venom resistance in a rattlesnake predator and its squirrel prey. *Proceedings of the Royal Society B: Biological Sciences*, *283*(1829), 20152841.

Huxoll, C. (2012). 2011 prairie dog shooting survey. South Dakota Wildlife Report No. 2012-08. South Dakota Department of Game, Fish and Parks.

Idaho Department of Fish and Game. (2017). *Idaho state wildlife action plan, 2015*. Boise, ID: Idaho Department of Fish and Game.

Idaho Department of Fish and Game. (2019). Ground squirrel hunting. Retrieved from https://idfg.idaho.gov/hunt/ground-squirrel.

Jenni, D. A., Redmond, R. L., & Bicak, T. K. (1981). Behavioral ecology and habitat relationships of Long-billed Curlews in western Idaho. Department of Interior: Bureau of Land Management, Boise, ID.

Jochimsen, D. M., Peterson, C. R., & Harmon, L. J. (2014). Influence of ecology and landscape on snake road mortality in a sagebrush-steppe ecosystem. *Animal Conservation*, *17*(6), 583–592.

Knick, S. T., & Rotenberry, J. T. (2000). Ghosts of habitats past: Contribution of landscape change to current habitats used by shrubland birds. *Ecology*, *81*(1), 220–227.

Knight, B. L., & Gutzwiller, K. J. (Eds.). (1995). *Wildlife and recreationists*. Washington, DC: Island Press.

Knopper, L. D., Mineau, P., Scheuhammer, A. M., Bond, D. E., & McKinnon, D. T. (2006). Carcasses of shot Richardson's ground squirrels may pose lead hazards to scavenging hawks. *The Journal of Wildlife Management*, *70*(1), 295–299.

Kochert, M. N., & Pellant, M. (1986). Multiple use in the Snake River Birds of Prey Area. *Rangelands Archives*, *8*(5), 217–220.

Kochert, M. N., & Steenhof, K. (2003). *Long-term nesting population and productivity changes of prairie falcons and golden eagles in the Snake River NCA*. 2002 report. Unpublished agency report, U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Snake River Field Station, Boise, ID.

Kochert, M. N., & Steenhof, K. (2004). *Long-term nesting population and productivity changes of prairie falcons and golden eagles in the Snake River NCA*: 2003 report. U.S. Geological Survey Forest and Rangeland Ecosystem Science Center, Snake River Field Station, Boise, ID.

Lee, R. B., & DeVore, I. (Eds.). (1968). *Man the hunter. The first intensive survey of a single, crucial stage of human development—Man's once universal hunting way of life*. Aldine Transaction: Chicago, IL.

McTee, M., Hiller, B., & Ramsey, P. (2019). Free lunch, may contain lead: Scavenging shot small mammals. *The Journal of Wildlife Management*, *83*(6), 1466–1473.

Niraj, S. K., Sethi, S., Goyal, S. P., & Choudhary, A. N. (2019). Poaching, illegal wildlife trade, and bushmeat hunting in India and South Asia. In J. L. Koprowski & P. R. Krausman (Eds.), *International wildlife management: Conservation challenges in a changing world*. Baltimore, MD: Johns Hopkins University Press.

North American Bird Conservation Initiative (NABCI). (2016). *The state of North America's birds 2016*. Ottawa, Canada: Environment and Climate Change Canada. Retrieved from www.stateofthebirds.org

Nyhus, P. J. (2016). Human–wildlife conflict and coexistence. *Annual Review of Environment and Resources*, *41*, 143–171.

Ogada, D., Shaw, P., Beyers, R. L., Buij, R., Murn, C., Thiollay, J. M., … Krüger, S. C. (2016). Another continental

vulture crisis: Africa's vultures collapsing toward extinction. *Conservation Letters*, *9*(2), 89–97.
Olson, C. (1999). Human-related causes of raptor mortality in western Montana: Things are not always as they seem. In R. L. Carlton (Ed.), *Avian interactions with utility and communication structures (pp. 299–322)* (pp. 85–103). Concord, CA: EPRI Technical Report.
Page, G. W., Warnock, N., Tibbitts, T. L., Jorgensen, D., Hartman, C. A., & Stenzel, L. E. (2014). Annual migratory patterns of long-billed curlews in the American West. *The Condor: Ornithological Applications*, *116*(1), 50–61.
Paprocki, N., Glenn, N. F., Atkinson, E. C., Strickler, K. M., Watson, C., & Heath, J. A. (2015). Changing habitat use associated with distributional shifts of wintering raptors. *The Journal of Wildlife Management*, *79*(3), 402–412.
Parker, W. S., & Brown, W. S. (1973). Species composition and population changes in two complexes of snake hibernacula in northern Utah. *Herpetologica*, *29*, 319–326.
Pauli, B. P., Sun, E. R., Tinkle, Z. K., Forbey, J. S., Demps, K. E., & Heath, J. A. (2019). Human habitat selection: Using tools from wildlife ecology to predict recreation in natural landscapes. *Natural Areas Journal*, *39*(2), 142–149.
Pearce-Higgins, J. W., Brown, D. J., Douglas, D. J., Alves, J. A., Bellio, M., Bocher, P., … Dann, P. (2017). A global threats overview for Numeniini populations: Synthesising expert knowledge for a group of declining migratory birds. *Bird Conservation International*, *27*(1), 6–34.
Pelicice, F. M., Azevedo-Santos, V. M., Vitule, J. R., Orsi, M. L., Lima Junior, D. P., Magalhães, A. L., … Agostinho, A. A. (2017). Neotropical freshwater fishes imperilled by unsustainable policies. *Fish and Fisheries*, *18*(6), 1119–1133.
Phelps, J., Biggs, D., & Webb, E. L. (2016). Tools and terms for understanding illegal wildlife trade. *Frontiers in Ecology and the Environment*, *14*(9), 479–489.
Pilliod, D. S., Welty, J. L., & Arkle, R. S. (2017). Refining the cheatgrass–fire cycle in the Great Basin: Precipitation timing and fine fuel composition predict wildfire trends. *Ecology and Evolution*, *7*(19), 8126–8151.
Pollock, J., Miller, R. A., & Carlisle, J. D. (2014). *2014 abundance and productivity of long-billed curlews (Numenius americanus) in the Long-billed Curlew Habitat Area of Critical Environmental Concern of Southwest Idaho*. 2014 Annual Report, Intermountain Bird Observatory, Boise State University, Boise, ID.
R Core Team. (2018). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.
Redmond, R. L., & Jenni, D. A. (1986). Population ecology of the Long-billed Curlew (*Numenius americanus*) in western Idaho. *The Auk*, *103*(4), 755–767.
Redpath, S. M., Young, J., Evely, A., Adams, W. M., Sutherland, W. J., Whitehouse, A., … Gutierrez, R. J. (2013). Understanding and managing conservation conflicts. *Trends in Ecology & Evolution*, *28*(2), 100–109.
Reiserer, R. S., Schuett, G. W., & Earley, R. L. (2008). Dynamic aggregations of newborn sibling rattlesnakes exhibit stable thermoregulatory properties. *Journal of Zoology*, *274*(3), 277–283.
Ripple, W. J., Abernethy, K., Betts, M. G., Chapron, G., Dirzo, R., Galetti, M., … Newsome, T. M. (2016). Bushmeat hunting and extinction risk to the world's mammals. *Royal Society Open Science*, *3*(10), 160498.
Ritchie, E. G., & Johnson, C. N. (2009). Predator interactions, mesopredator release and biodiversity conservation. *Ecology Letters*, *12*(9), 982–998.
Rudolph, B. A., & Riley, S. J. (2017). Gaining compliance and cooperation with regulated wildlife harvest. In M. L. Gore (Ed.), *Conservation criminology* (pp. 77–96). West Sussex, England: John Wiley & Sons.
Russell, R. E., & Franson, J. C. (2014). Causes of mortality in eagles submitted to the National Wildlife Health Center 1975–2013. *Wildlife Society Bulletin*, *38*(4), 697–704.
Sasaki, K., Place, A. J., & Gaylor, K. N. (2008). Attitudes toward rattlesnakes by the peoples of North America and implications for rattlesnake conservation. In W. K. Hayes, K. R. Beaman, M. D. Cardwell, & S. P. Bush (Eds.), *The biology of rattlesnakes symposium* (pp. 473–484). Loma Linda, CA: Loma Linda University Press.
Sauer, J. R., Niven, D. K., Hines, J. E., Ziolkowski, D. J., Jr., Pardieck, K. L., Fallon, J. E., & Link, W. A. (2017). *The North American Breeding Bird Survey, results and analysis 1966-2015*. Laurel, MD: USGS Patuxent Wildlife Research Center.
Scheuhammer, A. M., Bond, D. E., Burgess, N. M., & Rodrigue, J. (2003). Lead and stable lead isotope ratios in soil, earthworms, and bones of American woodcock (*Scolopax minor*) from eastern Canada. *Environmental Toxicology and Chemistry*, *22*(11), 2585–2591.
Selonen, S., & Setälä, H. (2015). Soil processes and tree growth at shooting ranges in a boreal forest reflect contamination history and lead-induced changes in soil food webs. *Science of the Total Environment*, *518*, 320–327.
Simon, K. L., Best, D. A., Sikarskie, J. G., Pittman, H. T., Bowerman, W. W., Cooley, T. M., & Stolz, S. (2020). Sources of mortality in bald eagles in Michigan, 1986–2017. *The Journal of Wildlife Management*, *84*(3), 553–561.
Sutton, G. M. (1928). Notes on a collection of hawks from Schuylkill County, Pennsylvania. *The Wilson Bulletin*, *40*(2), 84–95.
Theng, M., Glikman, J. A., & Milner-Gulland, E. J. (2018). Exploring saiga horn consumption in Singapore. *Oryx*, *52*(4), 736–743.
Treves, A., Artelle, K. A., Darimont, C. T., & Parsons, D. R. (2017). Mismeasured mortality: Correcting estimates of wolf poaching in the United States. *Journal of Mammalogy*, *98*(5), 1256–1264.
U.S. Bureau of Land Management. (2008). Snake River Birds of Prey National Conservation Area resource management plan and record of decision. US BLM, Boise District Office, Boise, ID.
U.S. Bureau of Land Management. (2014). *Idaho special status animal species: 2014 change 1*. Boise, ID: US BLM Idaho State Office. Retrieved from https://www.blm.gov/download/file/fid/12084
U.S. Fish and Wildlife Service. (2016). *Bald and golden eagles: Population demographics and estimation of sustainable take in the United States, 2016 update*. Washington DC: Division of Migratory Bird Management.
Vosburgh, T. C., & Irby, L. R. (1998). Effects of recreational shooting on prairie dog colonies. *The Journal of Wildlife Management*, *62*(1), 363–372.
Warwick, C., Steedman, C., & Holford, T. (1991). Rattlesnake collection drives—Their implications for species and environmental conservation. *Oryx*, *25*(1), 39–44.

Watson, C., Atkinson, E. C., Steenhof, K., & Rotenberry, J. T. (1996). Abundance and distribution of raptors and ravens across the ISA benchlands, 1991–1994. Chapter 4 F. In K. Steenhof (Ed.), *BLM/IDARNG project final report* (Vol. 2). Boise, ID: U.S. Geological Survey, Snake River Field Station.

Whitfield, D. P., & Fielding, A. H. (2017). Analyses of the fates of satellite tracked golden eagles in Scotland. Scottish Natural Heritage Commissioned Report No. 982.

Wyoming Game and Fish Department (WGFD). (2019). Agency web page. Retrieved from https://wgfd.wyo.gov/

Yensen, E., Quinney, D. L., Johnson, K., Timmerman, K., & Steenhof, K. (1992). Fire, vegetation changes, and population fluctuations of Townsend's ground squirrels. *American Midland Naturalist*, *128*(2), 299–312.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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APPENDIX

Study area

Native land cover in lower elevations of southwestern Idaho is high desert sagebrush (*Artemesia* spp.) shrub-steppe on volcanic and alluvial soils. In the recent past, the landscape has been heavily altered by human use and by invasion of non-native annual grasses and warming trends that have, together, contributed to dramatic changes in fire frequency. These stressors have changed the floral communities, with knock-on effects on faunal communities. Today, vegetation is dominated by annual cheatgrass (*B. tectorum*) communities, with small remaining patches of woody *Artemisia* shrubs in unburned areas. These vegetative communities, relict and invasive, support large numbers of Piute ground squirrels (*Urocitellus mollis*), and burrowing and shrub-grass dwelling avian, mammalian, and reptilian species.

Southwestern Idaho also has a number of conservation areas on public lands, and our data collection occurred in two of these. The Morley Nelson Snake River Birds of Prey National Conservation Area (NCA), a nearly 200,000 ha protected area, was established south of Boise, Idaho (Figure 1) in 1993. It was created to support the dense concentrations of prairie falcons (*Falco mexicanus*) and other birds of prey that nest on cliffs of igneous volcanic rock along the 130 km of the Snake River Canyon (Kochert & Steenhof, 2003). The Long-billed Curlew Habitat Area of Critical Environmental Concern (ACEC), a ~25,000 ha protected area, was established northwest of Boise (Figure 1) by the Bureau of Land Management in 1988 because of its significance as a nesting area for long-billed curlews (*Numenius americanus*). Habitat there is predominantly non-native annual grassland, but the ACEC is bordered by agricultural fields that provide important foraging habitat for curlews.

Both the NCA and the ACEC support large numbers of Piute ground squirrels and their predators, including carnivorous mammals and birds of prey. Recreational shooting of ground squirrels is common in both areas.

Long-billed curlew

In southwestern Idaho, long-billed curlews arrive from wintering areas in the latter half of March and nest from early April through mid-June (Coates, Wright, & Carlisle, 2019). As large birds, curlews are relatively conspicuous on the landscape, but especially in spring, during display or courtship flights, or when they have young. Curlews can be aggressive and highly visible when humans or potential predators are close to their vulnerable young, often mobbing, performing distraction displays, and alarm calling.

To understand causes of population declines, studies of curlew ecology and behavior have been conducted since 2009, focused especially in the ACEC and NCA (Figure 1; Pollock, Miller, & Carlisle, 2014; Coates, Hayes, et al., 2019). Nest monitoring shows evidence of declines of hatching rates in the ACEC, from 40% in the late 1970s (Redmond & Jenni, 1986) to 23% more recently (Coates, Hayes, et al., 2019; Coates, Wright, & Carlisle, 2019; Pollock, Miller, & Carlisle, 2014).

Avian assemblage

The large numbers of ground squirrels, mountain cottontails (*Sylvilagus nuttallii*), and black-tailed jackrabbits (*Lepus californicus*) at the NCA provide forage for one of the world's greatest concentrations of nesting raptors. Birds of prey that nest in the area include red-tailed hawk (*Buteo jamaisensis*), ferruginous hawk (*B. regalis*), Swainson's hawk (*B. swainsoni*), golden eagle (*Aquila chrysaetos*), northern harrier (*Circus hudsonius*), short-eared owl (*Asio flammeus*), burrowing owl (*Athene cunicularia*), prairie falcon, and American kestrel (*Falco sparverius*; Kochert & Pellant, 1986; Kochert & Steenhof, 2004). Populations of many of these species are declining, locally and nationally (Sauer et al., 2017). Raven (*Cordus Corax*) are also abundant and, apparently, increasing throughout southwestern Idaho and the Great Basin (Sauer et al., 2017). The region is an important wintering area for many of these same species, as well as for rough-legged hawk (*B. lagopus*; Bureau of Land Management, 2008; Paprocki et al., 2015). Although ground squirrels are still numerous, the Leporids are far less common than they once were, and diet of some raptors has changed in response to these changes in the prey base (Heath & Kochert, 2016).

Snakes

The Great Basin rattlesnake (*Crotalus oreganus lutosus*) is a venomous pit viper (family Viperidae; subfamily Crotalinae) that inhabits southern Idaho and parts of Arizona, California, Nevada, Oregon, and Utah. Like other rattlesnakes, members of this species have sensory pit organs on each side of their head, and they subdue prey with a specialized toxic venom (Holding, Biardi, & Gibbs, 2016). Their eponymous rattle, which is composed of specialized, loosely connected segments of keratin, is used to alarm or distract possible predators or other animals that may cause them harm. When defensive signaling fails, rattlesnakes will strike and occasionally envenomate nonprey animals, including humans (Glaudas, Farrell, & May, 2005; Hayes, Herbert, Rehling, & Gennaro, 2002).

Great Basin rattlesnakes have characteristics that make them vulnerable to mortality from humans. First, they tend to congregate at certain times of the year, making persecution of many individuals possible. They give birth to live young, mother snakes remain with the young for several weeks, and they overwinter communally, often in rocky hibernacula with other snake species (Clark, Brown, Stechert, & Greene, 2012; Hamilton & Nowak, 2009; Reiserer, Schuett, & Earley, 2008). Large numbers of snakes congregate at hibernacula in the fall when temperatures are dropping, and they tend to linger near hibernacula in the spring so that they can reenter dens to avoid cold temperatures (Parker & Brown, 1973). Second, rattlesnakes spend time in visible locations on roads, to gather heat stored in dense asphalt material. In southeastern Idaho, Great Basin rattlesnakes and Great Basin gopher snakes (*Pituophis catenifer deserticola*) are the two species most commonly found dead on roads (Jochimsen, Peterson, & Harmon, 2014). Anthropogenic mortality appears to be demographically relevant. A study in Utah documented the 22-year decline of Great Basin rattlesnakes at a hibernaculum and associated that decline with overcollection and human-related mortality, especially hunting (Brown & Parker, 1982; Parker & Brown, 1973).

Harvesting rattlesnakes for personal use can be legal under Idaho Code with an Idaho hunting license. Typically, license holders are allowed to possess up to four live or dead animals or up to six skins for sale or barter (Idaho Code CH2, SECT36-201, amended June 2010). Idaho rules for rattlesnakes were amended in June 2019 prohibiting the killing of rattlesnakes (Idaho Code 36-201, classification of wildlife amended June 2019; Idaho Administrative Code 13.01.100). It is difficult to know the legality of the snake killing we recorded, but at least some appear not to have been in compliance with state law (e.g., the May 2015 and 2016 events; Officer C. Justus, personal communication).