Received: 20 June 2023 | Revised: 2 January 2024 | Accepted: 2 January 2024

DOI: 10.1002/jwmg.22552

RESEARCH ARTICLE

THE JOURNAL OF WILDLIFE MANAGEMENT

THE WILDLIFE SOCIETY

Bear deterrence with scare devices, a non-lethal tool in the use-of-force continuum

Wesley M. Sarmento

Montana Fish Wildlife and Parks, 514 S Front Street, Conrad, MT 59425, USA

Correspondence
Wesley M. Sarmento, Montana Fish Wildlife and Parks, 514 S Front Street, Conrad, MT 59425, USA.
Email: wmsarmento@gmail.com

Funding information
U.S. Fish and Wildlife Service; Montana Outdoor Legacy Foundation; Safari Club International Foundation; Montana Fish, Wildlife and Parks; Vital Ground Foundation

Abstract

Wild animals eating agricultural products and coming close to people's residences are primary causes of human–wildlife conflict worldwide. When carnivores eat anthropogenic foods and cause human safety concerns, it often results in the removal of the animals and public demand for reduced wildlife populations. The use of remote methods, such as scare devices, to deter carnivores has been touted in the literature; however, efficacy evidence remains thin. I test the efficacy of a widely available motion-activated solar alarm lamp to deter grizzly bears (*Ursus arctos*) from farms in Montana, USA. When scare devices were activated, there was a 46% reduction in the odds bears would access an attractant. For every additional scare device, there was an additional 44% reduction in the odds of a bear getting the food. Additionally, scare devices caused bears to be more vigilant and increase movement behavior. More bears in a group led to loss of deterrence efficacy, and there was no evidence for habituation to the aversive stimuli. This deterrence method was most effective in August and for fungicide-treated wheat. Out of 21 farms, scare devices stopped bears from returning to 11 sites. Overall, scare devices can be a cheap and easy first step to preventing, or resolving, some grizzly bear issues in the use-of-force continuum, which hierarchically organizes conflict responses from non-lethal to more severe.

KEYWORDS

aversive conditioning, conflict prevention, grizzly bears, human–wildlife conflict, human–wildlife interaction, landscape of fear, scare device, wildlife management

Wildlife–human conflict is a pressing issue worldwide when human activities encroach on natural habitats or wild animal populations increase. Conflicts can result in damage to property, crops, livestock, and even human injury or death. Real and perceived conflicts are one of the leading causes of wildlife declines globally and can significantly influence human livelihoods (Dickman 2010). Conserving species that harm people and damage property is a serious sociopolitical challenge (Treves and Karanth 2003). Large mammals that cause conflict often exist on or near agricultural lands where people have traditional value systems, engrained identities, and economic hardship, and often perceive threats much differently than urban dwellers (Volski et al. 2021). To enable coexistence between wildlife and people, it is important that conservation practitioners work with local constituents to mitigate wildlife issues when they occur and prevent problems before they happen (Venumière-Lefebvre et al. 2022).

Large carnivores are particularly prone to human–wildlife conflict because of their predatory nature, large home ranges, and potential danger to people (Treves and Karanth 2003). With the arrival of European settlers in North America, carnivores were heavily persecuted by people and their habitat was reduced (Woodroffe 2000). In more recent times, a growing understanding of the role carnivores play in ecosystems and societal interest has led to some populations gaining protection, which has resulted in their recovery from historical lows (Ingeman et al. 2022). Grizzly bears (*Ursus arctos*) were protected in the Rocky Mountains in the United States in 1975 (Bjornlie et al. 2014). Since gaining protections grizzly populations have increased in some areas and are now expanding out from the mountains back onto their traditional prairie habitat, which is occupied by people and agricultural production (Nesbitt et al. 2023). While the recovery of grizzlies is a conservation success, it has also been a significant social challenge because increasing bear numbers has led to more conflicts and considerable fear among the people that live with them (Young et al. 2015, Sarmento and Carney 2017).

In Montana, USA, east of the Rocky Mountain Front is known as the breadbasket because of the high production of grain crops such as wheat, barely, lentils, sunflower, and chickpeas. The transportation and storage of these crops frequently leads to spilled grain near farmstead homes. Constrained by limited manpower and tools, it is not always feasible for producers to clean up spilled grain. These large piles of spilled grain are a significant attractant for grizzly bears looking for easy high-calorie meals. Bears eating the discarded grain is not necessarily a conflict because most producers consider the spills waste. When grain causes bears to come close to human settlements, however, it leads to concern for people's safety. With dozens of bears eating discarded grain in central Montana, the relocation or removal of all these individuals is not a feasible management approach. Beyond basic constraints of time and equipment, relocation sites are limited and often bears return to the locations of easily available food sources (Milligan et al. 2018). Additionally, removing 1 bear from a grain spill does not resolve the issue long-term when other bears are bound to show up and use the same unsecured attractant. On the other hand, it is necessary to prevent bears from coming close to people to reduce the chance of encounters and address concerns about human safety, which increases tolerance for the species (Young et al. 2015). This growing issue has caused a need to find solutions and test ways of deterring bears from feeding on these agricultural foods.

In response to human–wildlife conflicts, a variety of remote deterrent systems have been attempted worldwide to deter animals from approaching human settlements. These devices are designed to elicit a fear response in wildlife, with the hope that the risk stimuli will cause them to reduce their use of the area. Remote deterrent methods have been used for a wide range of wildlife species, including but not limited to deer, birds, rodents, bears, and coyotes (*Canis latrans*). These deterrent systems can be categorized into 4 types: visual, auditory, physical, and chemical. Visual devices are perhaps the oldest method with the use of scarecrows dating back centuries. More modern visual devices typically employ movement or flashing lights to scare animals. Auditory devices emit loud noises. Common sound deterrence systems include sirens and propane cannons. Physical systems result in some sort of contact with the animal, which can include water or an electric shock. Finally, chemical methods use odor or taste aversion to discourage animals from approaching attractants. Chemical repellents contain compounds that are unpleasant or noxious to wildlife. Some deterrence systems combine negative stimuli, such as lights and sounds.

Several studies have been conducted to evaluate the effectiveness of remote scare methods at deterring wildlife (Table 1). The results have been mixed, with some researchers reporting high efficacy rates and others

TABLE 1 Database of peer-reviewed research from 1990–2023 testing remote deterrents on carnivores worldwide obtained through a literature search on Google Scholar. I included the following terms in the search: carnivore*, scare*, deterrent*, and repellent*. The asterisk denotes that automatic stemming used in the search; thus, all related words would be included. Effect denotes whether the deterrent had the intended influence (i.e., kept carnivores away from people or prevented livestock loss).

Location	Species	Scare type	Method	Effect	Key finding	References
United Kingdom	Badgers (*Meles meles*)	Chemical	Ziram paste	Mixed	Reduced corn damage	Baker et al. (2005)
Australia	Captive dingoes (*Canis lupus dingo*)	Chemical	Guard dog urine	No	No evidence for predator repellent from dog urine	Van Bommel and Johnson (2017)
Spain	Captive wolves	Chemical	Levamisole	Yes	4 of 5 wolves avoided treated meat for 1 month	Tobajas et al. (2020)
North Carolina, USA	Coyotes	Chemical	Wolf scat	No	Wolf scat did not deter mesocarnivores	Louis et al. (2020)
Norway	Wolverines (*Gulo gulo*)	Chemical	Volatile repellents	Yes	Reduced livestock loss by 14%	Landa and Tømmerås (1996)
Multiple	Multiple	Physical, chemical, auditory	Multiple	Mixed	Not considered effective long-term, large-scale	Smith et al. (2000)
Namibia	Black-backed jackal (*Canis mesomelas*), caracal (*Caracal caracal*)	Visual	Foxlights	Yes	Reduced livestock loss	Verschueren et al. (2021)
Utah, USA	Captive coyotes	Visual	Fladry	Yes	Reduce fladry spacing	Young et al. (2019)
California, USA	Coyotes	Visual	Foxlights	Yes, weak	No predation near lights, but little reduction in activity	Volski et al. (2021)
Kenya	Large carnivores	Visual	Flashing lights	No	Lights did not significantly reduce predator activity	Wanjira et al. (2021)
India	Leopards (*Panthera pardus*)	Visual	Foxlights	Yes	Devices reduced livestock loss roughly 50%	Naha et al. (2020)
Kenya	Lion, other carnivores	Visual	LED lights	Yes	Devices reduced livestock loss by roughly 50%	Okemwa et al. (2018)
Kenya	Lions (*Panthera leo*)	Visual	Light-emitting diode (LED) lights	Yes	Devices reduced livestock loss roughly 90%	Lesilau et al. (2018)

(Continues)

TABLE 1 (Continued)

Location	Species	Scare type	Method	Effect	Key finding	References
Chile	Pumas (*Puma concolor*), Andean foxes (*Lycalopex culpaeus*)	Visual	Flashing lights	Mixed	Pumas discouraged, not foxes	Ohrens et al. (2019)
Australia	Red foxes (*Vulpes vulpes*)	Visual	Foxlights and spotlights	No	Fox activity increased at foxlight sites	Hall and Fleming (2021)
China	Tibetan brown bears (*Ursus arctos pruinosus*)	Visual	Multiple	Mixed	Interviewees considered solar lights 80% effective	Dai et al. (2022)
Alberta	Wolves	Visual	Fladry	Yes	Fladry provided up to 60 days of protection	Musiani et al. (2003)
Greece	Wolves	Visual	Fladry	Yes	Wolf approaches reduced 75%	Illopoulos et al. (2019)
Michigan, USA	Wolves, coyotes	Visual	Fladry	Mixed	Fladry provided up to 75 days of protection from wolves	Davidson-Nelson and Gehring (2010)
Utah, USA	Captive coyotes	Visual, auditory	Lights and sound boxes	Yes	Combined lights and sounds most effective	Darrow and Shivik (2009)
Australia	Captive dingoes	Visual, auditory	Gun shot noise, inflatable human effigy	Mixed	Auditory device ineffective, effigy reduced feeding	Smith et al. (2020)
Mexico	Felids	Visual, auditory	Multiple	Yes	No livestock loss at sites with scare devices	Zarco-González and Monroy-Vilchis (2014)
Wisconsin, USA	Wolves	Visual, auditory	Movement-activated guard	Yes	Scare device reduced feeding roughly 60%	Shivik et al. (2003)
British Columbia	Coyotes	Visual, physical	Sprinkler	Yes	Reduced activity	McLellan and Walker (2021)
Germany	Wolves	Visual, physical	Multiple	Yes	Fladry most effective	Bruns et al. (2020)
Wisconsin and Michigan, USA	Wolves	Visual, physical	Fladry	Yes	Fladry provided at least 90 days of protection	Gehring et al. (2006)

reporting little to no effect (Smith et al. 2000). The lack of consensus on the effectiveness of scare systems may be attributed to several factors such as the type of device used, the target species, the environment in which they are used, and study design. Despite mixed evidence, scare devices have been touted as a highly effective solution to conflict management (Lorand et al. 2022). Yet the effectiveness of these different systems at deterring wildlife remains unclear, particularly for new devices or novel situations such as grizzly bears obtaining grain on the prairie.

A wide variety of scare systems have been tested to reduce carnivore conflicts mostly on agricultural lands. Chemical deterrents appeared to be the least effective and the most difficult to deploy on large scale (Van Bommel and Johnson 2017, Louis et al. 2020). These chemical methods would be impossible to deploy on all the grain spills across central Montana to provide consistent aversion to grain. Furthermore, chemical deterrents fade over time, which takes more human effort to maintain compared to electronic scare systems.

Physical scare devices have received the least amount of attention apart from systems that deliver shocks. Electric fences are not so much a scare method as they are barriers. For grain spills on farms, electric fence barriers are often not a practical solution to deter bears because producers need frequent, easy access to storage bins with large trucks and farming equipment. One study tested the use of a widely available motion-activated sprinkler system (McLellan and Walker 2021); however, water is too limited in Montana for this to be an option.

Visual frightening devices have been the most common system tested with several different designs. Fladry hanging on rope or on an electrified wire was widely studied for wolf (*Canis lupus*) deterrence and appears to be effective for a couple months until animals become habituated to the stimuli (Musiani et al. 2003, Davidson-Nelson and Gehring 2010, Iliopoulos et al. 2019, Young et al. 2019). Light scare systems were also tested widely but showed more mixed evidence for efficacy. Felids were more responsive to light (Lesilau et al. 2017, Ohrens et al 2019, Naha et al. 2020), whereas canids did not appear discouraged (Hall and Fleming 2021, Volski et al. 2021). The difference between the species is possibly due to felids being secretive ambush predators. Devices that emitted both sounds and light appeared to be more effective than systems that did one or the other (Smith et al. 2000, Darrow and Shivik 2009). It does not appear that audio-visual scare devices have been tested quantitatively on any ursid species worldwide.

To address this knowledge gap, I tested the efficacy of an affordable and widely available audio-visual scare device at preventing grizzly bears from accessing agricultural foods on farms. Scare devices may be particularly useful because they are automated, so they do not require constant monitoring from people. My objective was to contribute to developing best practices for minimizing human–carnivore conflicts by determining if, and when, the scare device would be effective at deterring grizzlies from site attractants.

STUDY AREA

I carried out this study in the prairie ecoregion of north-central Montana, where grizzly bears are expanding out onto private lands from the Northern Continental Divide Ecosystem, which includes the Bob Marshall Wilderness Complex and Glacier National Park. Complaints about grizzly bears in the region average about 80 annually, and conflicts in the area are gradually increasing (Sarmento and Carney 2017). Bears have been observed >100 km from the mountains and sightings far from recovery zones are increasing (W. M. Sarmento, unpublished data). This population consisted of >1,000 grizzly bears (Costello and Roberts 2021) and was protected as threatened under the Endangered Species Act. The prairie area where this study took place was approximately 28,116 km^2 in size with an elevation range of 792–1,525 m and was characterized by a semi-arid continental climate with about 30 cm of precipitation annually. Annual seasons include winter (Dec–Feb), spring (Mar–May), summer (Jun–Aug), and autumn (Sep–Nov). The land cover was primarily cropland, wooded riparian areas, and grasslands typical of the northern Great Plains. The topography is largely flat except for river valleys and occasional hills. Major native grasses included needle-and-thread (*Stipa comata*), blue grama (*Bouteloua gracilis*), and western wheatgrass (*Agropyron smithii*). Waterways were dominated by cottonwood trees (*Populus* spp.) and shrubs important to grizzlies including chokecherry (*Prunus virginiana*), serviceberry (*Amelanchier* spp.), and buffaloberry (*Shepherdia* spp.). Many farmsteads had cultivated shrubs, primarily Siberian peashrub (*Caragana* spp.) for windbreaks. Common crops included wheat species, barley, lentils, chickpeas, sunflower, and flax. There were a few small towns with <3,000 people each, and several smaller villages with around 300 people each. Most agricultural producers lived out of towns on their farms or ranches. Large mammalian wild fauna consisted of whitetail deer (*Odocoileus virginianus*), mule deer (*O. hemionus*), elk (*Cervus canadensis*), moose (*Alces alces*), and coyotes.

METHODS

I deployed motion-activated solar alarm lamps (model GM-228-2p-B07W9KLXRB; Eugen, China) from 2019–2022 at farms in response to public complaints or based on occurrences of satellite-collared grizzly bears using unsecured agricultural attractants. I selected the solar alarm lamps because of their affordability (US$15/unit), weather resistance, solar powered batteries, motion activation, and ability to be switched to night mode only (Figure 1). These units had 6 flashing red light-emitting diode (LED) lights (180 lumens), a 129-decibel siren, and an 8-m motion-sensing range. Once triggered the lights and sirens operated for 40 seconds. I set the devices to operate only at night because typically bears access anthropogenic attractants under the cover of darkness, and because agricultural producers did not want alarms going off from human presence during the day. I deployed scare devices 1 m from ground level, within 1 m from the food source, and pointed directly at the food source. If a structure was present, I attached the scare device to it; otherwise, I installed them on a metal fence post. The number of scare devices deployed at each location was randomly varied *ad libitum* and based on available equipment, which ranged

FIGURE 1 Example of solar alarm lamp scare devices deployed in a typical initial management response to a public complaint of a grizzly bear eating spilled grain in north-central Montana, USA, from 2019–2022.

from 1–4. I installed a Bushnell trophy camera HD (Bushnell Corporation, Overland Park, KS, USA) next to the scare device and set it to video night mode only and on normal sensitivity, which allowed the recording to start before the scare device went off. Thus, the camera would trigger from motion at 30.5 m, whereas the alarm would trigger at 8 m. The videos were set to record for 30 seconds, with a 30-second interval between recordings. I left scare devices and cameras deployed for 4-136 days at sites. Some scare devices were not turned on properly by field staff, which allowed for a control test (deployed but not activated) of the units. I was able to determine if the scare device was turned on by observing the lights and sound in the videos.

I collected various covariates and response variables related to the situation from site visits and from the camera videos. Variables included location coordinates, date and time of a bear visit, number of devices, attractant type, attractant amount, age and sex of bear, number of bears (group composition), behavior at the end of the video, and whether the food attractant was accessed. I categorized bear behaviors into feeding, vigilant (head at or above shoulders and not chewing), and moving (on all 4 feet, walking or running). I recorded only the behavior at the end of the video, unless the bear left the frame of the video, and in those cases, I recorded the last behavior observed (i.e., if the bear fled halfway through the video, I recorded it as moving behavior). I determined sex and age of an individual bear through established criteria (Alaska Department of Fish and Game 2015). If I could not determine sex and age, then those variables were categorized as unknown. The type of attractant included wheat grain, wheat treated with fungicide, trash, carcasses, lentils, mineral cake for livestock, birdseed, and compost. Sample sizes were too small for some attractant types (e.g., trash, carcasses, lentils, mineral cake, compost, and birdseed) to be run separately so I grouped those together as other attractants. I included attractant type (wheat, treated-wheat, other attractant) to determine if bears were more likely to risk getting higher calorie foods. I estimated the amount of attractant with a measuring tape or from volume removed. Occasionally the attractant was removed, sometimes days after devices were first deployed, which I noted in the amount available to the bears. Month was categorical and included June through November. I recorded the number of days devices were deployed and if the power of the devices were on, or off, during videos. Complete removal of all grain was not feasible because it mixed in with gravel and grass; therefore, some remnants always remained. I did not include site name in analysis because of limited sample size. I used location coordinates to include additional landscape variables of distance to streams and distance to cover using ArcMap Geographic Information Systems 10 (Esri, Redlands, CA, USA). As animals may engage in riskier behaviors when escape cover is available, I tested for an effect of distance from attractants to riparian areas, which bears use for security (Northrup et al. 2012).

Following methods from Volski et al. (2021), I ensured independence of samples by only including the first video from each 15-minute interval in analysis. If a bear accessed the attractant in any video, regardless of being the sample video, then I noted the access and included it in analyses. I considered an attractant accessed if a bear fed. Conversely, if a bear fled, I considered it scared off. I conducted all statistical analyses in the program R version 4.2.1 (R Core Team 2020). I used a generalized linear binomial model with logit link to test the efficacy of scare devices at preventing bears from accessing attractants. I included all occurrences of bears on the camera and responses were 1 if feeding on attractants was observed, and 0 if feeding did not occur. Starting with a global model that contained all independent variables, I removed nonsignificant variables ($P > 0.1$) in a backward stepwise fashion, until only significant variables remained, monitoring the coefficients, significances, and log-likelihood of models for large changes with each removal (Hosmer and Lemeshow 2013). I tested independence of variables in all models using 3 thresholds: a variance inflation factor of <10, correlation between variables of <30%, and whether coefficient estimates changed >20% with the removal of covariates (Bursac et al. 2008). I examined diagnostic plots to confirm residuals were normally distributed and that outliers were not unjustifiably influencing statistical outputs (Hosmer and Lemeshow 2013). For non-independent variables I ran separate global models without the correlated covariates to assess relative performance. Then, I discarded overly correlated variables and only retained the better preforming covariates for backward stepwise model selection. I ranked models using small sample size-corrected Akaike's Information Criterion (AIC_c). I selected the top-ranked model and considered covariates with a $P \geq 0.01$ to be uncertain and less informative. I also ran the top model with the lower preforming correlated variables. Finally, I used a chi-square test to understand if bear behavior at the end of samples was different between instances where scare device power was on or off.

RESULTS

After screening out hundreds of non-independent videos there were 447 videos left across 21 farms. Scare devices deterred bears from accessing attractants from 11 farms, while bears at 10 of the farms obtained unsecured attractants. Scare device power was on in 226 samples and off in 221 samples. I observed males in 177 videos, females in 137 videos, and bears of unknown sex in 133 videos. Samples included 259 adults, 130 subadults, 38 yearlings, and 20 bears of unknown age. The average group size was 1.42 ± 0.03 (SE) bears. Most samples (n = 316) included lone bears, while 74 included 2 bears, 56 included 3 bears, and 1 sample had a group of 4 bears. The average amount of unsecured attractant was 1,006.79 ± 7.75 kg (SE).

Behavior at the end of samples was different when the scare device power was on versus off ($\chi^2 = 26.141$, $P \leq 0.01$). When scare devices were activated, bear behavior at the end of sample was 27% feeding, 46% moving, and 10% vigilant. When scare devices were off, bear behavior at the end of sample was 46% feeding, while moving and vigilance decreased to 41% and 5%, respectively.

I competed 10 models to explain when unsecured agricultural attractants were accessed by grizzly bears (Table 2). The top model included scare device power, group size, number of scare devices, type of attractant, distance to stream, month, and days the devices were deployed. Month and type of attractant had higher uncertainty in the top model due to lower sample sizes for these variables. Effect sizes indicated that activated scare devices caused a 46% reduction in the odds an attractant would be accessed (Table 3). For every additional scare device, there was an additional 44% reduction in the odds of a bear getting the food. Each additional bear resulted in an increase of 1.66 times in the odds of an attractant being acquired. Bears were less likely to eat fungicide-treated wheat relative to untreated wheat. Also, the odds grizzlies would acquire attractants was 95% less

TABLE 2 Candidate models explaining whether a grizzly bear acquired an agricultural attractant on farms in north-central Montana, USA, 2019-2022. Models are ranked by difference in small size-corrected Akaike's Information Criterion (ΔAIC_c) based on log likelihood (LL) and number of parameters (K).

Model[a]	K	AIC_c	ΔAIC_c	LL
Power + group + scares + type + distance to stream + month + days deployed	13	531.10	0.00	−252.13
Power + group + scares + type + distance to cover + distance to stream + month + days deployed	14	532.00	0.90	−251.51
Power + group + scares + type + month + days deployed	12	532.02	0.92	−253.65
Power + group + amount + scares + type + distance to cover + distance to stream + month + days deployed	15	532.61	1.51	−250.75
Power + age + sex + amount + distance to stream + days deployed	10	567.59	36.49	−273.54
Power + age + sex + distance to stream + days deployed	9	567.85	36.75	−274.72
Power + age + sex + amount + distance to cover + distance to stream + days deployed	11	568.24	37.13	−272.82
Power + age + sex + days deployed	8	569.50	38.39	−276.58
Power + age + sex + amount + scares + distance to cover + distance to stream + days deployed	12	570.25	39.15	−272.77
Null	1	621.57	90.47	−309.78

[a]Variables include whether the scare device was turned on or off (power), the number of bears in a group (group), the number of scare devices deployed (scares), the type of agricultural attractant involved (type), distance to stream, month, how long scare devices were left up (days deployed), distance to cover, the amount of attractant that was available to bears (amount), and age and sex of bear.

TABLE 3 Results from a generalized linear binomial model with logit link explaining whether a grizzly bear acquired an agricultural attractant on farms in north-central Montana, USA, 2019–2022. Baseline parameters are wheat for attractant type, scare device power off, and the month of June.

Covariate	β	SE	Z	P
Intercept	1.20	0.64	1.89	0.06
Power on	−0.61	0.24	−2.59	0.01
Group size	0.98	0.20	5.01	<0.01
Number of devices	−0.57	0.14	−4.03	<0.01
Other attractant	−0.53	0.85	−0.63	0.53
Treated wheat attractant	−1.14	0.30	−3.77	<0.01
Stream distance (100 m)	−0.10	0.06	−1.57	0.12
August	−3.07	0.91	−3.39	<0.01
July	−0.25	0.68	−0.37	0.71
November	−0.56	0.85	−0.66	0.51
October	0.38	0.64	0.59	0.56
September	−0.66	0.63	−1.05	0.29
Days devices deployed	−0.01	0.01	−2.47	0.01

in August relative to June. The odds a bear would get an attractant was reduced 1% for each additional day after a scare device was initially deployed.

DISCUSSION

The results of this study and others provide evidence that scare devices have some efficacy at deterring carnivores from agricultural attractants and livestock *in situ*. With an affordable and widely available scare device, the odds a grizzly bear would use grain spills and other attractants was reduced by 46%. Grizzly bears were frequently scared off by these devices. Furthermore, the devices caused a change in bear behavior, where individuals decreased feeding and increased vigilance and movement. These simple deterrence systems were highly cost-effective, saved time, and increased human safety by deterring some bears from concentrated but unsecured attractants.

Overall, grain is a particularly difficult attractant to secure, yet scare devices show promise at efficiently reducing some bear issues. Removing the attractant is typically the most effective option at reducing bear use; however, farmers and conservation practitioners are often short on time to continuously clean up thousands of pounds of spilled grain on every farm. During harvest, farmers are working day and night to harvest crops before the yield is reduced from environmental factors. It can take 8–16 hours to clean up a single large grain spill, and often more grain is spilled shortly afterward. Furthermore, it is difficult to clean up all the grain on gravel surfaces and even with an industrial vacuum, some grain is still leftover, which the bears can obtain. Since 2018, the Montana Fish, Wildlife and Parks has removed roughly 10,000 kg of spilled grain annually to prevent bears from coming near people, yet this action is not feasible across the entire geographic area or as a long-term mitigation plan (W. M. Sarmento, unpublished data). Most grain spills can be prevented with a heavy-duty tarp placed under the auger boot; however, the practice is not widespread (W. M. Sarmento, unpublished data). Programs that provide tarps and education on their use are currently in place to help increase the practice. Other attractants are similarly difficult to secure (e.g., fruit trees, garbage cans).

Use of force continuum theory is a military and enforcement protocol that organizes the level of response an agency should apply to a specific conflict (Terrill and Paoline 2013) and can be a useful model for bear management actions. For human–bear conflict, responses can be organized from low level (preventive efforts) to moderate level (hazing and relocation) to high level (removal of an individual). These data suggest basic scare devices are a quick, easy, cheap, and effective initial, low-level response to a complaint involving bears accessing unsecured agricultural attractants. Other bear managers, however, insist that a high-level response first is the ideal approach to reduce ursids from accessing attractants (Spencer et al. 2007). High-level responses, however, are typically labor intensive and are also not 100% effective. For example, bears often travel widely each night; thus, setting a trap for a bear that may not return to the conflict site for weeks can be a poor use of resources. These results suggest that bears did not habituate to the scare devices over time; however, this may be an artifact of sampling. Because this study was performed during management situations, the top priority was to deter bears from people as opposed to perfect study design. Therefore, conflict response started with scare devices and then sometimes incorporated additional actions. If bears were failing to respond to the frightening systems and removal of the attractant, then use of force was increased. On several occasions bears were not responding to scare devices so they were hazed. On a couple of occasions where hazing and scare devices were not effective, bears were captured and relocated. Furthermore, bears begin to hibernate in October, with most bears entering dens by December; thus, individual bears naturally leave the area over time regardless of the presence of scare devices. For these reasons, it is possible the amount of time scare devices were deployed was negatively correlated with bear use of grain. Scare systems were particularly effective in August, which is when chokecherries are most abundant, suggesting that scare devices work better when natural foods are readily available.

These results generally conform to what would be expected based on foraging and population distribution theories. Distance to streams was retained in the top model, and its retention suggests that when bears are farther from their security habitat, they are more responsive to fear stimuli (Sarmento and Berger 2020). Foraging theory would predict that bears should be more willing to engage in risk for higher value food (Lima and Dill 1990), which these data suggest is the case as scare devices were more effective on fungicide-treated wheat. The treated wheat likely causes some illness in bears, yet they frequently feed on the fungicide- and insecticide-laced seed stock. Also conforming to research on other species, bears appeared to be less fearful when in larger groups (Sarmento and Berger 2017). The simplest explanation is a strength in numbers concept, where risk is reduced through grouping up. Conversely, a reduction in scare device efficacy with larger group sizes could also be interpreted in the context of ideal despotic distribution where subordinate animals are forced to forage in riskier places because they are displaced from better habitat by dominate animals (Beckman and Berger 2003). Larger groups of bears are most often associated with either dispersing subadults or adult females with young, both of which are typically subordinate to adult males.

Scare devices appear to have mixed effects on deterring carnivores from agricultural areas (Smith et al. 2000, Naha et al. 2020). Like many of the other studies, ours was not performed to the highest experimental standard possible because the bear management team was responding to real-world complaints with human safety being the top priority. Some of those articles suggested absolute or near perfect deterrence, which are likely flawed conclusions based on small studies with few replicates or short sampling periods (e.g, Zarco-Gonzalez Monroy-Vilchis 2014). Of the studies with higher quality designs, there were about 40–60% reductions in predator activity reported (Shivik et al. 2003, Naha et al. 2020), which is what was found in this study.

Scare systems can help keep people and agricultural commodities safe, while also preventing the need for relocations or removals of wildlife. These devices should be a tool in any wildlife management program, as it is a cost-effective starting point for responding to complaints. There may be situations where stronger management action is warranted more quickly (e.g., children are present, the bear lacks fear of people) and thus the use of scare devices should not be prescribed or mandated. Knowing when to use scare devices depends on interpretation by managers and knowledge of the professionals on the ground who understand wildlife behavior and regularly respond to these highly emotional and potentially dangerous situations. Every human–wildlife conflict is different and therefore it is important to provide flexibility to practitioners so they can tailor each response to the specific conditions present. Working with local communities to develop and deploy tools to deter apex predators and prevent or stop conflict is essential to gaining buy-in and building tolerance for these controversial species.

More work needs to be done on scare devices, as many of these systems show promise but are currently rudimentary. Future development should focus on building a widely available and affordable scare device that can be more programable. Specifically, a scare device that can be easily loaded with various audio clips, such as humans yelling, dogs barking, or conspecific alarm calls, could prove more effective. Currently, no programmable store-bought system exists on the market despite the widespread need. The device could randomly play an audio clip when motion-activated to lessen the chance of habituation. Additionally, bear spray has shown strong effects at deterring bears (Smith et al. 2008); it is possible that these could be incorporated into a remote and automated deterrence system that only deploys on target species using artificial intelligence. Testing new systems will be essential. Additionally, more robust research on deterrence methods is needed. Testing deterrence systems on collared individuals will greatly improve our understanding of these tools.

MANAGEMENT IMPLICATIONS

Store-bought, motion-activated light and sound scare devices, represent an easy and somewhat effective way to deter carnivore activity from concentrated attractants, although the systems in their current form do not represent a perfect solution for stopping predators. My study did not find an influence of attractant amount on efficacy; however, I was focused on small, concentrated attractants where scare devices had good coverage. The efficacy of these scare devices is likely reduced when the attractant is large (e.g., entire crops, grain bin complexes). Based on these analyses, I recommend deployment of ≥4 audio-visual scare devices at once because for every additional scare device, there was an additional 44% predicted reduction in the odds of a bear getting the food. Conservation practitioners should anticipate that the efficacy of frightening devices will be reduced with the quality of attractant, when natural foods are unavailable, and when more individuals approach together. Overall, the devices reduced feeding and deterred bears from farms about half the time. Some animals were not deterred by the scare devices, which required higher levels of force. Removing or securing attractants and hazing helped deter persistent animals, while a few continued to use farms. Animals that become food conditioned and habituated to people may need to be relocated or removed from the population if they consistently use non-natural foods, lose fear of people, and do not respond to conflict response approaches.

ACKNOWLEDGMENTS

The literature search was performed by E. N. Fenger. S. J. Zielke, D. J. McHugh, and A. J. Marschner, and J. R. Austin assisted with deploying cameras, scare devices, and entering data. Thanks to J. A. Gude, C. M. Costello, C. A. White, H. S. Cooley, C. M. Loecker, and other biologists, managers, and support staff for their general assistance. Thanks to J. B. Stetz, P. R. Krausman, A. S. Cox, and 2 anonymous reviewers for greatly improving this manuscript. Much gratitude to the local community for their tolerance for bears and willingness to try these devices. This project was funded by the United State Fish and Wildlife Service, Vital Ground Foundation, Montana Fish, Wildlife, and Parks, Montana Outdoor Legacy Foundation, and Safari Club International Foundation.

CONFLICT OF INTEREST STATEMENT

The author declares no conflicts of interest.

ETHICS STATEMENT

This scare device program was conducted with the permission of the United States Fish and Wildlife Service (annual 4(d) permit). All grizzly bears were handled following protocols approved by the Montana Animal Care and Use Committee (Montana Fish Wildlife and Parks 2004).

DATA AVAILABILITY STATEMENT

Some data supporting this research are sensitive and not available publicly. Location data of grizzly bears and sampling locations on private land are owned by Montana, Fish, Wildlife and Parks and may be available to qualified researchers by contacting Public Records Team Lead, 1-406-444-4069 or gail.eblen@mt.gov, and requesting Region 4 Conrad office grizzly bear scare device data from 2019–2022. All state laws apply. Anonymized data will be archived on figshare.

ORCID

Wesley M. Sarmento http://orcid.org/0000-0002-0967-3581

REFERENCES

Alaska Department of Fish and Game. 2015. Brown bear: identifying males and females in the field. Alaska Department of Fish and Game, Anchorage, USA.

Baker, S. E., S. A. Ellwood, R. W. Watkins, and D. W. Macdonald. 2005. A dose–response trial with ziram-treated maize and free-ranging European badgers *Meles meles*. Applied Animal Behaviour Science 93:309–321.

Beckmann, J. P., and J. Berger. 2003. Using black bears to test ideal-free distribution models experimentally. Journal of Mammalogy 84:594–606.

Bjornlie, D. D., D. J. Thompson, M. A. Haroldson, C. C. Schwartz, K. A. Gunther, S. L. Cain, D. B. Tyers, and B. C. Aber. 2014. Methods to estimate distribution and range extent of grizzly bears in the Greater Yellowstone Ecosystem. Wildlife Society Bulletin 38:182–187.

Bruns, A., M. Waltert, and I. Khorozyan. 2020. The effectiveness of livestock protection measures against wolves (*Canis lupus*) and implications for their co-existence with humans. Global Ecology and Conservation 21:e00868.

Bursac, Z., C. H. Gauss, D. K. Williams, and D. W. Hosmer. 2008. Purposeful selection of variables in logistic regression. Source Code for Biology and Medicine 3:1–8.

Costello, C. M., and L. L. Roberts. 2021. Northern Continental Divide Ecosystem grizzly bear population monitoring team annual report. Montana, Fish, Wildlife and Parks, Kalispell, USA.

Dai, Y., Y. Li, Y. Xue, C. E. Hacker, C. Li, B. Zahoor, Y. Liu, D. Li, and D. Li. 2022. Mitigation strategies for human–Tibetan brown bear (*Ursus arctos pruinosus*) conflicts in the hinterland of the Qinghai-Tibetan Plateau. Animals 12:1422.

Darrow, P. A., and J. A. Shivik. 2009. Bold, shy, and persistent: variable coyote response to light and sound stimuli. Applied Animal Behaviour Science 116:82–87.

Davidson-Nelson, S. J., and T. M. Gehring. 2010. Testing fladry as a nonlethal management tool for wolves and coyotes in Michigan. Human-Wildlife Interactions 4:87–94.

Dickman, A. J. 2010. Complexities of conflict: the importance of considering social factors for effectively resolving human–wildlife conflict. Animal Conservation 13:458–466.

Gehring, T. M., J. E. Hawley, S.J. Davidson, S T. Rossler, A. C. Cellar, R. N. Schultz, A. P. Wydeven, and K. C. VerCauteren. 2006. Are viable non-lethal management tools available for reducing wolf-human conflict? Preliminary results from field experiments. Pages 2–6 in Proceedings of the vertebrate pest conference. University of California Agriculture & Natural Resources, 6 February—7 February, Davis, California, USA.

Hall, K. J., and P. A. Fleming. 2021. In the spotlight: Can lights be used to mitigate fox predation on a free-range piggery? Applied Animal Behaviour Science 242:105420.

Hosmer, D. W., and S. Lemeshow. 2013. Applied logistic regression. Second edition. John Wiley & Sons, New York, New York, USA.

Iliopoulos, Y., C. Astaras, Y. Lazarou, M. Petridou, S. Kazantzidis, and M. Waltert 2019. Tools for co-existence: fladry corrals efficiently repel wild wolves (*Canis lupus*) from experimental baiting sites. Wildlife Research 46:484–498.

Ingeman, K. E., L. Z. Zhao, C. Wolf, D. R. Williams, A. L. Ritger, W. J. Ripple, K. L. Kopecky, E. M. Dillon, B. P. DiFiore, J. S. Curtis, and S. R. Csik. 2022. Glimmers of hope in large carnivore recoveries. Scientific Reports 12:10005.

Landa, A., and B. Å. Tømmerås. 1996. Do volatile repellents reduce wolverine *Gulo gulo* predation on sheep? Wildlife Biology 2:119–126.

Lesilau, F., M. Fonck, M. Gatta, C. Musyoki, M. van't Zelfde, G. A. Persoon, K. C. Musters, G. R. De Snoo, and H. H. De Iongh. 2018. Effectiveness of a LED flashlight technique in reducing livestock depredation by lions (*Panthera leo*) around Nairobi National Park, Kenya. PLoS One 13:e0190898.

Lima, S. L., and L. M. Dill. 1990. Behavioral decisions made under the risk of predation: a review and prospectus. Canadian Journal of Zoology 68:619–640.

Lorand, C., A. Robert, A. Gastineau, J. B. Mihoub, and C. Bessa-Gomes. 2022. Effectiveness of interventions for managing human-large carnivore conflicts worldwide: scare them off, don't remove them. Science of the Total Environment 838:156195.

Louis, M.M., S. M. Tucker, M. K. Stoskopf, and S. Kennedy-Stoskopf. 2020. Evaluating red wolf scat to deter coyote access to urban pastureland. Human–Wildlife Interactions 14:9.

McLellan, B. A., and K. A. Walker. 2021. Efficacy of motion-activated sprinklers as a humane deterrent for urban coyotes. Human Dimensions of Wildlife 26:76–83.

Milligan, S., L. Brown, D. Hobson, P. Frame, and G. Stenhouse. 2018. Factors affecting the success of grizzly bear translocations. Journal of Wildlife Management 82:519–530.

Montana Fish Wildlife and Parks. 2004. Biomedical protocol for free-ranging Ursidae in Montana: black bears (*Ursus americanusUrsus arctos horribilis*) and grizzly bears (): capture, anesthesia, surgery, tagging, sampling, and necropsy procedures. Montana Fish Wildlife and Parks, Helena, USA.

Musiani, M., C. Mamo, L. Boitani, C. Callaghan, C. C. Gates, L. Mattei, E. Visalberghi, S. Breck, and G. Volpi. 2003. Wolf depredation trends and the use of fladry barriers to protect livestock in western North America. Conservation Biology 17:1538–1547.

Naha, D., P. Chaudhary, G. Sonker, and S. Sathyakumar. 2020. Effectiveness of non-lethal predator deterrents to reduce livestock losses to leopard attacks within a multiple-use landscape of the Himalayan region. PeerJ 8:e9544.

Nesbitt, H. K., A. L. Metcalf, E. C. Metcalf, C. M. Costello, L. L. Roberts, M. S. Lewis, and J. A. Gude. 2023. Human dimensions of grizzly bear conservation: the social factors underlying satisfaction and coexistence beliefs in Montana, USA. Conservation Science and Practice 5:e12885.

Northrup, J., G. Stenhouse, and M. Boyce. 2012. Agricultural lands as ecological traps for grizzly bears. Animal Conservation 15:369–377.

Ohrens, O., C. Bonacic, and A. Treves. 2019. Non-lethal defense of livestock against predators: flashing lights deter puma attacks in Chile. Frontiers in Ecology and the Environment 17:32–38.

Okemwa, B., N. Gichuki, M. Virani, J. Kanya, J. Kinyamario, and A. Santangeli. 2018. Effectiveness of LED lights on bomas in protecting livestock from predation in southern Kenya. Conservation Evidence 15:39–42.

Sarmento, W. M., and J. Berger. 2017. Human visitation limits the utility of protected areas as ecological baselines. Biological Conservation 212:316–326.

Sarmento, W. M., and D. Carney. 2017. Patterns and spatial prediction of livestock predation by grizzly bears on the Blackfeet Reservation. Intermountain Journal of Sciences 23:85.

Sarmento, W., and J. Berger. 2020. Conservation implications of using an imitation carnivore to assess rarely used refuges as critical habitat features in an alpine ungulate. PeerJ 8:e9296.

Shivik, J. A., A. Treves, and P. Callahan. 2003. Nonlethal techniques for managing predation: primary and secondary repellents. Conservation Biology 17:1531–1537.

Smith, B. P., N. B. Jaques, R. G. Appleby, S. Morris, and N. R. Jordan. 2020. Automated shepherds: responses of captive dingoes to sound and an inflatable, moving effigy. Pacific Conservation Biology 27:195–201.

Smith, M. E., J. D. Linnell, J. Odden, and J. E. Swenson. 2000. Review of methods to reduce livestock depredation II. Aversive conditioning, deterrents and repellents. Animal Science 50:304–315.

Smith, T. S., S. Herrero, T. D. Debruyn, and J. M. Wilder. 2008. Efficacy of bear deterrent spray in Alaska. Journal of Wildlife Management 72:640–645.

Spencer, R. D., R. A. Beausoleil, and D. A. Martorello. 2007. How agencies respond to human–black bear conflicts: a survey of wildlife agencies in North America. Ursus 18:217–229.

R Core Team. 2020. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Terrill, W., and E. A. Paoline III. 2013. Examining less lethal force policy and the force continuum: results from a national use-of-force study. Police Quarterly 16:38–65.

Tobajas, J., M. J. Ruiz-Aguilera, J. V. López-Bao, P. Ferreras, and R. Mateo. 2020. The effectiveness of conditioned aversion in wolves: insights from experimental tests. Behavioural Processes 181:104259.

Treves, A., and K. U. Karanth. 2003. Human-carnivore conflict and perspectives on carnivore management worldwide. Conservation Biology 17:1491–1499.

Van Bommel, L., and C. N. Johnson. 2017. Olfactory communication to protect livestock: dingo response to urine marks of livestock guardian dogs. Australian Mammalogy 39:219–226.

Venumière-Lefebvre, C. C., S. W. Breck, and K. R. Crooks. 2022. A systematic map of human-carnivore coexistence. Biological Conservation 268:109515.

Verschueren, S., C. Torres-Uribe, W. D. Briers-Louw, G. Fleury, B. Cristescu, and L. Marker 2021. Flashing lights to deter small stock depredation in communal farmlands of Namibia. Conservation Evidence Journal 18:50–51.

Volski, L., A. McInturff, K. M. Gaynor, V. Yovovich, and J. S. Brashares. 2021. Social effectiveness and human-wildlife conflict: linking the ecological effectiveness and social acceptability of livestock protection tools. Frontiers in Conservation Science 2:682210.

Wanjira, J., T. C. Ndiwa, N. Gichuki, and M. Wykstra. 2021. Evaluating the efficacy of flashing lights in deterring livestock attacks by predators: a case study of Meibae Community Conservancy, Northern Kenya. East African Journal of Science, Technology and Innovation 2:2707–0425.

Woodroffe, R. 2000. Predators and people: using human densities to interpret declines of large carnivores. Animal Conservation 3:165–173.

Young, J. K., J. Draper, and S. Breck. 2019. Mind the gap: experimental tests to improve efficacy of fladry for nonlethal management of coyotes. Wildlife Society Bulletin 43:265–271.

Young, J. K., Z. Ma, A. Laudati, and J. Berger. 2015. Human–carnivore interactions: lessons learned from communities in the American West. Human Dimensions of Wildlife 20:349–366.

Zarco-González, M., and O. Monroy-Vilchis. 2014. Effectiveness of low-cost deterrents in decreasing livestock predation by felids: a case in Central Mexico. Animal Conservation: 17:371–378.

Associate Editor: Jeffrey Stetz.

How to cite this article: Sarmento, W. M. 2024. Bear deterrence with scare devices, a non-lethal tool in the use-of-force continuum. Journal of Wildlife Management e22552. https://doi.org/10.1002/jwmg.22552