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Can an old dog learn a new trick? : Efficacy of livestock guardian dogs at keeping an apex predator away from people

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ABSTRACT

Historic practices to reduce dangerous interactions between people, livestock, and large carnivores are returning alongside the recovery of some large carnivore populations. Emerging novel scenarios where people and carnivores interact make it important to identify nonlethal tools to reduce risk to people and facilitate coexistence. We tested an ancient practice in a novel way by placing livestock guardian dogs (LGDs) at farmsteads (i.e., areas with a family home and grain bins) with chronic interactions with grizzly bears (*Ursus arctos*). Grizzly bears are attracted to spilled grains around storage bins, causing concern over human safety near homes. Although we were only able to place five LGDs at four farmsteads, we found several lines of evidence supporting the use of LGDs to deter bears and protect people. There were 58-fold fewer camera-trap detections of bears visiting farmsteads with LGDs and an increase in behaviors suggesting bear discomfort compared to paired neighbor farmsteads that did not receive an LGD (i.e., control sites). After LGDs were deployed, there was an 87.8 % reduction in GPS-collar locations of bears within 300 m of farmsteads relative to before. Farmers had a positive experience using LGDs and would recommend them to others. Our results suggest LGDs could serve to protect specific locations and offer a new use of an old tool, but we recommend further research to broaden the scope of inference because of the small sample size of this study.

1. Introduction

Due to the global decline of large carnivores over the last 5000 years, most human societies have forgotten ancient techniques to live with apex predators (Lambert and Berger, 2022). Recovery of large predators, alongside an increasing human population, has also resulted in increased human-carnivore interactions. When people and carnivores come into proximity to each other the result is often in conflict with human interests and safety, such as economic losses and human injury or death (Thirgood et al., 2005; Penteriani et al., 2016). These conflicts affect livelihoods and frequently result in decreased tolerance and/or targeted removal of the wildlife involved. The need for people to have safety from predators is fundamental, and today people are having to revisit these requirements as some populations of carnivores recover.

The recovery of grizzly bear (*Ursus arctos*) populations in the United States exemplifies the need to ensure human safety, reduce conflicts, and facilitate coexistence (Nesbitt et al., 2023). Grizzly bear populations continue to grow and expand their range, including a return to grassland prairies (Costello et al., 2022; Mace et al., 2017). While many prairie towns and communities in the United States have human populations that are aging and declining, there remains an abundance of people and farms. Prairie farmsteads (i.e., small areas with a farmhouse and grain bins) have food resources, including grain, livestock, orchards, and garbage, that are attractive to foraging bears. Grain is especially prevalent in and around prairie farming communities and is a highly attractive resource for bears (Gangadharan et al., 2017; Morehouse and Boyce, 2016), including females with cubs. Offspring may learn from their mother or be genetically predisposed to access grains, similar to the food-conditioning behavior of black bears (*Ursus americanus*; Hopkins III, 2013), which suggests this behavior will increase if bear populations continue to grow. Grain bins can be broken into by bears but bears usually access grain that is spilled in and around grain bins during the loading or unloading process. Bears have been observed bedding in open bins during the day. Bins are frequently visited by people, either when the grain is being stored or taken to market or because they are often built near farmhouses. Thus, there is a high likelihood of humans and grizzly bears interacting on farmsteads, which can compromise human safety and livelihoods (Morehouse and Boyce, 2016; Ugarte et al., 2019).

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Even though grizzly bear populations are increasing, they remain a protected species in the contiguous United States, including in the prairies. Threatened status under the Endangered Species Act adds complexity to mitigating issues that may arise. Because lethal removal of an endangered species is complex and a reactive response to a conflict that has already occurred, it may be more effective to remove the long-term risk of bear conflicts through non-lethal deterrents. However, non-lethal deterrents primarily focus on protecting livestock (Miller et al., 2016; van Eeden et al., 2018b; Young et al., 2015), and few are known to be effective at deterring bears away from residences.

Non-lethal deterrents offer proactive methods aimed at preventing conflicts from occurring. However, non-lethal deterrents to prevent access to a place or resource are often logistically and financially costly to install and maintain (Bogezi et al., 2021), and are prone to human error in their use. For example, barriers, such as electric fences, require high up-front costs, maintenance, and user knowledge. A fence works well at protecting livestock from bears (Khorozyan and Waltert, 2020), but a fence surrounding a home or farmstead may be too costly to install and maintain or may be too easily misused by the various people frequently going in and out of the protected area. Additionally, many agricultural producers do not want additional impediments to their daily operations. Non-lethal deterrents that are inexpensive and easy to use are best for widespread adoption (Scasta et al., 2017), yet few exist that have been tested for protecting people.

One highly effective and economical nonlethal deterrent with limited possibility for human error is a livestock guardian dog (LGD; *Canis familiaris* Moreira-Arce et al., 2018; van Eeden et al., 2018a). LGDs are successful at significantly reducing livestock depredation by large carnivores and facilitating coexistence (Kinka et al., 2021; Kinka and Young, 2019a; Spencer et al., 2020). Whether this behavior can transfer to protect stored grain and people at farmsteads is unknown. Other domestic dogs, such as Laika dogs in Russia, have been used historically to protect people from bears, but have been most recently used for lethal removal of bears (Gillin et al., 1997). While past use is promising, there are a few potential problems with applying LGDs at farmsteads. First, traditional breeds of LGDs – as their name implies – have been bred to bond to and protect livestock for centuries (Akyazi et al., 2018; Ivaşcu and Biro, 2020; Rigg, 2001). It is unknown if LGDs can generalize guarding behavior to protect farmsteads or if LGDs need the live-animal bond to prompt their protective behavior. LGDs may bond more to the herder than the livestock (Akyazi et al., 2018), which suggests they could protect people. However, LGDs protect livestock and not a specific territory where the livestock are grazing (Allen et al., 2016). Second, some owners of LGDs express concerns about the potential of LGDs to be aggressive towards humans and their pets. While aggressive behavior by LGDs towards people is rare (Andelt, 1992), if LGDs were to act aggressively towards humans or pets, the threat of aggression by an always-present LGD might be more concerning than the risk of an unlikely encounter with a grizzly bear. Third, some farmers are concerned that LGDs may roam too far from their homes. Although they typically do not roam far from the animals LGDs are protecting (van Bommel and Johnson, 2014; Young et al., 2019), farmsteads may have neighbors or busy roads nearby that would create a risk to a wandering LGD. Finally, there is concern among conservationists that LGDs will harass or harm nontarget wildlife (Smith et al., 2020), although these behaviors can be corrected (Whitehouse-Tedd et al., 2020). If these issues are either nonexistent or can be mitigated, many farmers own working and pet dogs already and may be able to adapt to using an LGD for human and resource protection.

We tested whether LGDs could reduce potential interactions between grizzly bears and people. Specifically, we placed LGDs at family farmsteads with a chronic history of bears accessing grain and other attractants next to their homes. Because of limitations on the number of LGDs that could be purchased and placed at treatment farmsteads, we used several data streams to measure the efficacy of LGDs at reducing bear access. We monitored LGD behavior to determine their space use via GPS-collars and behavior via focal observations and camera traps. We matched farmsteads given LGDs with neighbor farmsteads that did not receive LGDs to serve as controls and monitored activity of grizzly bears at both treatment group farmsteads using GPS-collar data from bears within 10-km of any participating control or treatment farmstead, and camera traps for presence/absence and behavioral data. We also recorded other carnivores detected on camera traps and interviewed farmers that were given LGDs. Our case study provides a roadmap for evaluating ancient preventative methods in novel ways that work directly with end-users to facilitate coexistence.

2. Material and methods

2.1. Study area

This case study was conducted with the permission of the United States Fish and Wildlife Service and Montana Fish, Wildlife and Parks under Utah State University Institutional Animal Use and Care Committee (Protocol Number 11956). We worked in the prairie ecoregion of North-Central Montana, USA, which is typical of northern great plains semi-arid environment. Landcover is mostly comprised of cultivated crops and grass. Main crops include various species of wheat, barely, lentils, chickpea, flaxseed, canola, and mustard. Primary native grasses include blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), and needle-and-thread (*Stipa comata*). Introduced forage species are mainly crested wheatgrass (*Agropyron cristatum*), alfalfa (*Medicago sativa*), and sainfoin (*Onobrychis viciifolia*). Cropland and grasslands are interrupted by river breaks mainly along the Sun, Teton, and Marias Rivers. Riparian vegetation is largely comprised of cottonwood trees (*Populus* spp.), chokecherry (*Prunus virginiana*), serviceberry (*Amelanchier* spp.), and buffaloberry (*Shepherdia* spp.). The study area is approximately 28,116 km^2 with elevations ranging from 792 to 1,525 m. Large mammalian wild fauna consists of whitetail deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), pronghorn (*Antilocapra americana*), and coyotes (*Canis latrans*). Grizzly bears in the area are a part of the Northern Continental Divide population which has over 1,000 individuals. Human population density is low and considered rural with livelihoods mainly consisting of crop and cattle production. There are a few towns with $<$ 3,000 people and about a dozen villages of $<$ 300 people.

2.2. Data collection

Starting in 2021, we identified farmsteads that had a history of grizzly bear presence, largely due to spilled grain that attracted the bears to this easy food source. We contacted the agricultural producers of these farmsteads and provided information on our research program, which included providing LGDs at no cost, assistance with LGD training, and all LGD expenses paid during the study (e.g., veterinary bills and dog food). Producers that agreed to participate were then provided with at least one LGD of Kangal, Boz, or Anatolian Sheperd breeds based on availability from reputable breeders. We chose these related LGD breeds because of past research suggesting they are successful at protecting livestock from large carnivores and well-liked by owners (Kinka and Young, 2019b). We deployed LGDs that were a year in age so they would be able to deter bears from the start of their placement. The LGDs were purchased from breeders who had typically housed the LGDs around small flocks of sheep, cattle, or goats. Participants agreed to provide good daily care for the LGDs and to take over maintenance costs after the research study was finished. We did not create specific guidelines for care and bonding with the LGDs, but most producers and their families worked with the LGDs on basic commands, petted and played with them regularly, and had pet dogs interact and play with the LGDs. LGDs were checked weekly for health issues and were taken to a veterinarian if needed. All dogs received surgeries to remove reproductive organs and were vaccinated for common dog ailments.

All treatment farmsteads were paired with a nearby (< 3 km) farmstead that had similar characteristics, but no LGDs. We placed one LGD at one farmstead on 7 April 2021 and collected data until 31 October 2021 and from 3 May – 31 October 2022. Although we had visited these two farmsteads before the study, we did not collect any preliminary data. These control and treatment farmsteads were 2280 m apart. In 2022, we placed LGDs at three additional farmsteads. Two farmsteads received one LGD each on 28 February 2022, while one farmstead received two LGDs, one on 25 May and the other on 22 June 2022. These three farmsteads were 1186 m, 1006 m, and 2290 m, respectively, from their paired control farmsteads. In 2022, we monitored four control and four treatment farmsteads and five LGDs until 31 October. To validate that grain availability was similar between control and treatment farmsteads, we compared the types of grain spilled and estimated the weight of spilled grain, calculated during each visit by measuring the diameter and depth of the spill. We visited treatment and control sites at least once a week during the months that grizzly bears were most active (April–October) in 2021 and 2022.

Global Positioning System (GPS) trackers (Tractive model # TRNJAWH) that were connected to cell phone networks were attached to LGD collars so they could be followed in real-time and to collect data on their movements. The LGDs wore GPS tracker collars between 3 May and 1 November 2022, except for the LGD that arrived later and was fitted with a tracker on 15 June 2022. If an LGD roamed too far beyond their homes, we installed a single wire containment system (Petsafe model # PIG00–13661) to keep the LGD around the areas in need of protection.

To quantify LGD behavior because of concerns from families living at farmsteads about the safety of owning an LGD with children and pet dogs also present at farmsteads, we conducted one 900-s focal observation on LGD during each visit (i.e., daylight hours). Behaviors included moving (walk and run), vigilant (head up), resting (sit or lying down), investigating (smelling or scratching), vocalizing (bark or howl), and human interactions (play, petting, other). At the start of our focal samples, we recorded covariates including location, number and age of people present, other dogs present, time, and temperature. We also recorded LGD activity and behavior from camera trap data, which was helpful to assess their behavior overnight.

To test if LGDs were effective at keeping bears away from farmsteads we deployed GPS-satellite collars (Telonics model # TGW-4577-4) on grizzly bears in the study area. Bears were captured using culvert traps between June 2020 and June 2022 and handled following approved protocols from Montana's Animal Use and Care Committee (Montana Fish, Wildlife, and Parks 2004). GPS-collars transmitted data when bears were not hibernating, from June–September 2020, March–November 2021, and April – November 2022. We used all GPS locations within 10-km of any farmstead for analysis of distances to farmsteads and the proportion of time bears spent at farmsteads.

Throughout each bear-activity season, we deployed four remote cameras (Bushnell model # 119837C) pointing at spilled grain or other agricultural attractants at each farmstead. Camera traps at the first paired control and treatment farmstead were set from 11 May to 1 November 2021 and at all four control and four treatment farmsteads from 11 to 25 May to 1 November 2022. Camera traps were also set from August 2021 to November 2021 at four farmsteads for preliminary data before half received an LGD and half served as a paired control in 2022. In both years, the cameras were checked weekly to ensure they were operational. Cameras were set to take a rapid burst of three photographs at once, with a 30-s interval between bursts, on normal sensitivity and night mode only because agricultural producers did not want photographs being taken of them working during the day. Producers self-reported daytime observations of grizzly bears.

From the photographs, we recorded the species and number of carnivore detections, as well as the behavior. Behaviors recorded for grizzly bears included feeding, vigilant (head up), running, walking, resting, interacting with other bears, and unknown. However, because of the low number of detections at farmsteads once LGDs were placed, we clumped behavior into one of three categories for analysis that would identify if bears responded to LGD presence: comfortable (feeding, resting, interacting with other bears), uncomfortable (vigilant, running), and other (walking and unknown).

At the end of the study, we provided questionnaires to study participants. We followed approved human study protocols (Utah State University #12979) when conducting the questionnaires. Surveys included 45 qualitative and quantitative questions regarding their opinions about their LGD and interactions with grizzly bears (SI Table 1).

2.3. Data analyses

All data were analyzed in Program R (version 4.2.1; R Core Team, 2023). We compared the amount of grain spilled at control versus treatment farms using a *t*-test to determine if control and treatment farmsteads had comparable grain resources available to bears. We calculated the distance LGDs were from farmsteads to determine the radius for fine-scale metrics of bear GPS-collar locations. To address the concerns of farmsteads owners about the safety of owning LGDs, we evaluated behavior of LGDs from focal observation data. We calculated the proportion of time LGDs spent in each behavioral category, then determined the proportion of time LGDs spent in each behavior to use in a mixed effects beta regression model using the glmmTMB package (Ver. 1.1.2; Brooks et al., 2017; Magnusson et al., 2017). We included fixed effects for number of people, distance to people, whether there was another dog (LGD, pet, or working dog) present, and whether the LGD was at or away from the house at the start of the focal observation. We used LGD identification as a random effect in all models. We report the top model for each behavior and any models within $\Delta AICc < 2$ of the top model. We combined all LGD behavior observed on camera traps that could be considered guarding behavior (patrolling, vigilant, smelling, and vocalizing) for statistical analysis. However, we had limited detections at control farmsteads, so only report summary statistics of LGD behavior.

We used GPS-location data from bear collars in two ways. First, we calculated the length of time bears were at control and treatment farmsteads before and once LGDs were placed. We considered a bear to be at a farmstead if the GPS-location was within 300 m of a farmstead. GPS-collars were scheduled to obtain fixes every two hours but some fixes were missed, so we calculated the step duration of consecutive locations and the time between the two steps. If the two GPS locations to define a step were both within 300 m from any farmstead, the value of time assigned was for the whole duration. If one of the two GPS locations was farther than 300 m, then the value was half of the duration. If both GPS locations were > 300 m, then the value was zero. We then summed these values to obtain four step metrics for each bear: control farmsteads, treatment farmsteads, before LGD placement, and after LGD placement. Second, to predict the proportion of GPS-locations from collared bears within 300 m and 1000 m of control versus treatment farmsteads before and after LGDs were placed, we used generalized linear models with the lme4 package (Bates et al., 2015) with pre- or after LGD placement and control/treatment farmsteads as fixed effects and BearID as a random effect. We used both distances with this analysis because 300 m represents the immediate footprint of the farmstead, while 1000 m included the footprint of the LGDs (i.e., included >90 % of all GPS-locations obtained from the LGDs).

To evaluate behavior of grizzly bears observed on camera traps, we fitted a logistic model for both comfortable and uncomfortable behaviors (estimated using ML and 'nlminb' optimizer). The response variable was the presence/absence of each behavior across all occasions of bear detection. The 95 % confidence intervals (CIs) and *p*-values were computed using a Wald z-distribution approximation.

Summary statistics are reported as average ± standard error.

3. Results

We confirmed that control and treatment farmsteads had similar grain spillage that could be an attractant to grizzly bears. An average of 55.9 ± 14.8 kg of grain was found per spillage check (n = 235) in 2021, with no difference between treatment and control farmsteads (t = 0.58, df = 227.63, p-value = 0.57). An average of 137.5 ± 21.7 kg of spillage was found per spillage check in 2022 (n = 332), with no difference between control and treatment farmsteads (t = −0.35, df = 239.82, p-value = 0.72). The primary grain spillage measured in both years across all farmsteads was wheat, although lentils and peas were also spilled. In 2022, corn, minerals, chickpeas, and mustard seeds were also spilled.

LGD GPS-Locations and Behavior.

We obtained 62,538 (range = 8,930–15,662/LGD) locations from GPS-tracker devices on LGDs. LGDs spent most of their time at their own farmstead; 91.3 ± 2.6 % of the GPS-collar locations were within 300 m of the treatment farmstead (i.e., LGD's home) and 95.4 ± 1.3 % were within 1000 m (Fig. 1). GPS-collar locations from LGDs also placed them near or at the control farmstead occasionally: 20.0 ± 19.9 % of the GPS-collar locations were within 300 m of the paired control farmstead (i.e., neighbor) and within 38.1 ± 23.3 % were within 1000 m (Fig. 1).

To quantify LGD behavior, we conducted 215 focal observations on the five LGDs. Moving, vigilant, and vocalizations only had one top model each. The intercept for moving, corresponding to other dog present is no, was at −3.26 (95 % CI: −3.78, −2.74); this intercept was significant and positive (Beta = 0.67, SE = 0.21, p = 0.001). For the vigilant model, the intercept, corresponding to other dog present is no, was at 1.84 (95%CI: 1.50, 2.27); the intercept was significant and positive (Beta = 0.53, SE = 0.16, p = 0.001). The null model was the best model for vocalizations. The best time spent smelling model included presence of other dog. The intercept, corresponding to other dog present is no, was at −4.42 (95 % CI: −4.97, −3.88); the intercept was not significant (Beta = 0.39, SE = 0.22, p = 0.08). The null model was within two AICc of the top model for smelling behavior. More than one model performed well for human interaction and resting behaviors. The null model was the top model for human interaction, but one other model that included presence of other dog was within two AICc (ΔAICc = 1.08). The model's intercept, corresponding to when other dog is present is no, was at −4.02 (95%CI: −4.49, −3.55); this intercept is not significant (Beta = 0.15, SE = 0.16, p = 0.34). The top model for resting behavior included whether the LGD was at or away from the house. The model's intercept, corresponding to away, was at −0.32 (95%CI: −0.89, 0.24); the intercept is not significant (Beta = 0.43, SE = 0.27, p = 0.11). The null model (ΔAICc = 0.49) and the model including whether another dog was present (ΔAICc = 0.69) were within two AICc of the top model for resting behavior. The model's intercept, corresponding to other dog present is no, was at 0.25 (95 % CI: −0.23, 0.74); the intercept was not significant (Beta = −0.35, SE = 0.25-, p = 0.31).

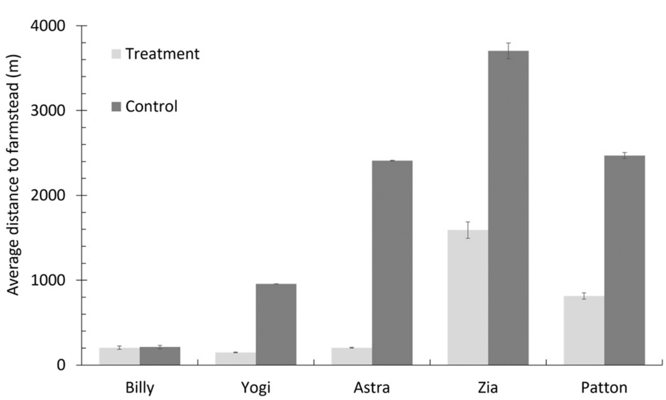

Fig. 1. Average distance (m; ± SE) each LGD was from its home (treatment) and neighbor farmsteads (control). LGDs were fitted with rechargeable GPS collars in 2021 (Billy only) and 2022 (all LGDs) to determine the landscape footprint of the LGDs.

LGDs were frequently detected on cameras at their home farmsteads (i.e., treatments; n = 4; range = 77–258 times) but were also detected one time at two of the three control farmsteads. Thus, while we could not statistically compare the behavior of LGDs across control and treatment locations because of the single events at control sites, we did observe some interesting behavior of LGDs at treatment farmsteads. Guarding behavior was observed in about one-third of the events (proportional range = 0.22–0.39). LGDs were most frequently observed moving (proportional range = 0.59–0.77), which may also be related to guarding behavior. Only one LGD roamed so much that a single-wire dog fence was installed and utilized in 2021.

3.1. *Grizzly bear GPS-locations and behavior*

Twelve bears that were fitted with GPS collars before or during this study were located within 10 km of at least one farmstead. Six provided data across the entire two years, while one dropped her GPS-collar before LGDs were placed and five were only fitted with collars once LGDs were placed on farmsteads. The number of GPS locations from each bear that were within 10 km of a control or treatment farmstead ranged from 218 to 3261 (n = 20,341 GPS locations). Before LGDs were placed, grizzly bears were an average of 5252.7 ± 58.8 m from control farmsteads and 5115.7 ± 58.9 m from treatment farmsteads. Once LGDs were placed, grizzly bears were located at farther average distances of 6459.5 ± 28.6 m from control and 6492.6 ± 26.1 m from treatment farmsteads. There were 41 GPS-locations when any collared bear was ≤ 300 m from a treatment farmstead before LGDs were in place (Fig. 2). These locations total approximately 11.9 ± 11.0 h of time. Remarkably, there were only 5 GPS-locations (from n = 7691) of collared bears ≤ 300 m from any treatment farmstead (Fig. 2), for approximately 0.7 ± 0.5 h, once LGDs were placed – an 87.8 % reduction in the number of GPS locations and 94.1 % reduction in the total time spent at the farmstead. This contrasts with the 52 GPS-locations (from n = 2370 total locations) of bears within 300 m of control farmsteads for approximately 19.2 ± 15.5 h before LGD placement and 40 GPS-locations (from n = 2371 total locations) for approximately 6.1 ± 3.4 h once LGDs were placed; only a 23.1 % reduction in the number of locations and 68.2 % reduction in time. Our models at 300 and 1000 m indicated three factors were significant (Table 1). First, there was a significant negative effect of LGD presence at 300 m, suggesting that grizzly bears were less likely to be at both control and treatment farmsteads after an LGD was placed. Second, there was a significant positive effect of treatment group at 1000 m, suggesting bears were more likely to be within 1000 m of treatment versus control farmsteads both before and once LGDs were present. Third, there was a significant negative effect for the interaction of LGD and treatment group at both distances, suggesting that grizzly bears were less likely to be at either distance of treatment farmsteads once LGDs were present, and the effect size suggests LGDs had a much stronger impact at treatment than control farmsteads (Table 1).

No grizzly bears were detected in 2021 via camera traps at the farmstead with an LGD, while they were detected 18.8 ± 2.8 times (n = 5, range = 9–25) at the farmsteads without LGDs. This includes nine and 21 detections at two farmsteads that received LGDs in 2022. Bears were typically observed moving (0.54 ± 0.13 proportion of detections) or eating (0.26 ± 0.11 proportion of detections). Also in 2021, bears were detected three and 51 times at two of the four control farmsteads, both of which remained as controls in 2022.

In 2022, grizzly bears were detected at least once at all farmsteads but detected 58-fold more times at control farmsteads than treatment farmsteads. Importantly, the behavior of grizzly bears at control farmsteads differed from treatment farmsteads. Bears at control sites were more frequently observed in comfortable behaviors (beta = −3.48, 95 % CI [−5.21, −1.76]; standard beta = −0.80, 95 % CI [−1.77, 0.17]). The model's intercept, corresponding to treatment group fitted for Control, is

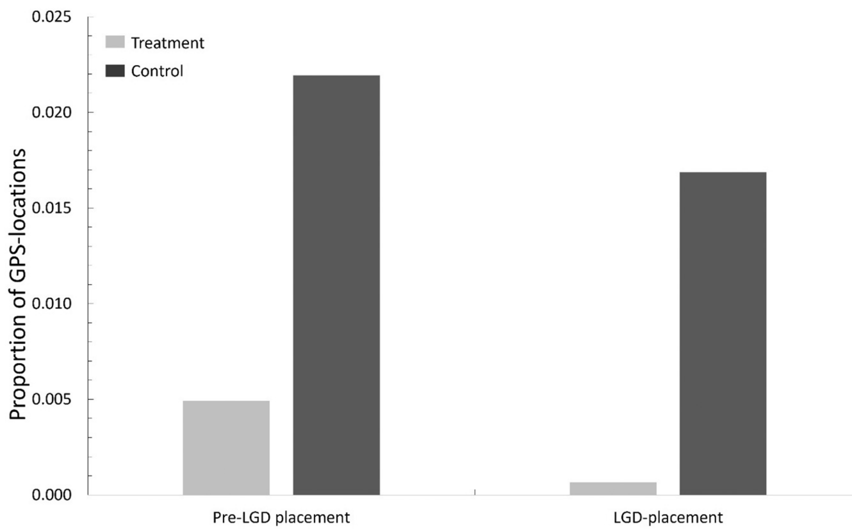

Fig. 2. The proportion of GPS-locations for grizzly bears ($n = 12$) when detected within 300 m from control (light colored bars) and treatment (dark colored bars) farmsteads before and after treatment farmsteads received a livestock guardian dog (LGD). Proportions were derived from all GPS-locations within 10-km of any participating farmstead. Grizzly bears were captured and fitted with GPS collars to obtain location data between 2020 and 2022, while farmsteads ($n = 8$) in Montana, USA, were evenly divided to receive an LGD or serve as a control in 2021 or 2022.

Table 1
Mixed effects logistic regression results for the probability of GPS-locations of grizzly bears being within 300 and 1000 m of control and treatment farmsteads before and once livestock guardian dogs were placed at treatment farmsteads.

	Variable	Estimate	SE	p-value
300 m	Intercept	−5.52	0.55	<0.001
	Before/After dog placement	−0.88	0.23	<0.001
	Control/Treatment	−0.26	0.21	0.225
	Before/After dog placement: Control/Treatment	−1.78	0.52	<0.001
1000 m	Intercept	−4.42	0.53	<0.001
	Before/After dog placement	0.04	0.12	0.716
	Control/Treatment	0.44	0.12	<0.001
	Before/After dog placement: Control/Treatment	−2.15	0.19	<0.001

at −0.80 (95 % CI [−1.77, 0.17]). Bears were more frequently observed in uncomfortable behaviors at treatment farmsteads (beta = 2.79, 95 % CI [1.07, 4.50]; standard beta = 0.67, 95 % CI [−0.42, 1.76]). The model's intercept, corresponding to treatment group fitted for Control, is at 3.57 (95 % CI [0.99, 12.84]).

3.2. Other wildlife detections

Other predator species - including raccoons, red foxes, coyotes, striped skunks, and owls - were detected on camera more frequently at treatment than control farmsteads. Red foxes were detected on nine occasions at treatment farmsteads. Coyotes were detected two and four times at two control farmsteads, with the farmstead having four detections receiving an LGD in 2022; coyotes were detected seven times at treatment farmsteads in 2022. Striped skunks were detected 17 times at treatment farmsteads and two times at control farmsteads. Raccoons were detected 116 times at treatment and 11 times at control farmsteads. An owl (unknown species) was detected one time at the treatment and at one control farmstead.

3.3. Farmer surveys

Farmer surveys were completed by the head of household at all four farmsteads that received the LGDs. Farmers who received LGDs ranged from 45 to 60 years of age and all had previously owned dogs (for 4–16 years leading up to the study). None of the farmers had LGDs previously because they had not considered it, had not needed it, or were worried about it being a hassle. Farmers reported they all had seen signs of grizzly bears for ≥ 3 years on their property, were concerned about children and livestock safety, thought there has been an increasing number of grizzly bears in their area over the past five years, and have had conflicts with grizzly bears on their property in past five years. They all reported that LGDs have decreased their grizzly bear problems and that owning an LGD is effective at reducing problems, but reported concerns with owning LGDs around the amount of food they eat, wandering behavior, and that LGDs can be "harsh" with other dogs. They also reported their LGDs knew little to no commands. The four farmers reported a benefit of LGDs is they keep bears out of their yards, that they would recommend LGD ownership to others, and plan to own another LGD in the future.

The farmer survey also included a series of questions for scoring statements on the Likert scale, a scale of 1–5 with 1 being strongly disagree and 5 being strongly agree (Table 2; SI Table 1). Scores were primarily strongly disagree or disagree on questions that would suggest the that LGDs are difficult to own (i.e., cause problems, exhibit undesirable behavior, etc). While scores were primarily strongly agree or agree that LGDs had positive traits around their ability to limit grizzly bear presence and their ability to behave in desirable ways around people and livestock. Responses were mixed for LGD gets along with dogs they regularly see, chases wildlife, are high energy at night, are submissive to other dogs, are the dominant dog, are food aggressive, and are playful. Only one head of household added a comment in the comment section, saying "We absolutely love these dogs and they were absolutely effective in keeping bears away."

4. Discussion

LGDs are an ancient practice used globally for traditional livestock protection (Ivaşcu and Biro, 2020; Kinka and Young, 2019a; Lieb et al., 2021; Rigg, 2001), but having LGDs protect farmsteads from apex predators is a technique that has been long forgotten in most parts of the world. Despite being an ancient technique, it has not been experimentally tested for protecting farmsteads before to our knowledge. The lack of experimental tests for nonlethal tools is common and may prevent deployment by end users (Eklund et al., 2017; van Eeden et al., 2018b). Experiments are logistically challenging to carry out when livelihoods

Table 2
Responses to questions on a Likert scale of 1–5, with 1 = strongly disagree, 2 = disagree, 3 = neutral, neither agree or disagree, 4 = agree, and 5 = strongly agree, from participants (n = 4) who received an LGD for their farmsteads in Montana. Questionnaires were completed after the study was completed in October 2022. NA = all participants scored the same, there was no range in answers.

Question	Average response	Range
My LGD is timid towards grizzly bears	1.50	1–3
My LGD is aggressive to grizzly bears	4.50	3–5
My LGD chases other predators than grizzly bears, like coyotes	4.25	3–5
My LGD chases wildlife, like deer, skunks, and small mammals	3.00	2–4
My LGD only barks when there is a possible threat (possible predator or an unfamiliar person or dog)	5.00	NA
My LGD barks much of the time (s)he is awake and active	1.25	1–2
My LGD likes to wander and walk long distances	3.50	2–5
My LGD gets along with other dogs that (s)he regularly sees	4.00	2–5
My LGD is the dominant dog	3.50	2–5
My LGD is submissive to other dogs	2.00	1–3
My LGD is aggressive to unfamiliar dogs	2.50	2–3
My LGD is timid towards people (s)he has never met before	3.25	2–4
My LGD is good with children	4.75	4–5
My LGD likes human attention (petting, play)	4.25	4–5
My LGD is high energy during the day	1.25	NA
My LGD is high energy during the night	4.00	3–5
My LGD is playful	3.25	2–4
My LGD harasses livestock	1.75	1–3
My LGD is smart	4.50	4–5
My LGD is food aggressive	4.25	3–5
My LGD likes to explore new things	4.25	3–5

are at stake, and may result in small sample sizes (e.g., Ohrens et al., 2019). To account for the small sample size in our study, we determined effectiveness through several metrics including the reduced presence of grizzly bears at farmsteads and farmer perception. Through our experimental design and data collection, we found multiple lines of evidence that LGDs are effective at reducing interactions between humans and grizzly bears at farmsteads. LGDs were effective despite an abundance of grain available via spillage at bins on farmsteads and previous visitations of grizzly bears to these farmsteads.

LGDs placed at farmsteads behaved similar to how LGDs behave in transhumance grazing systems (Kinka and Young, 2018). LGDs showed differences in time investigating, moving, and vigilant when another [pet] dog was present. This suggests LGDs are bonding to other dogs at the farmsteads and may affect desirable guarding behaviors when other dogs are present. Because these behaviors are helpful to patrolling and defense, these bonds may enforce the drive of the LGD to protect the farmstead. Bonding with other dogs would only be problematic if it disrupts guarding behavior. Because LGDs spent more time resting in the day, a behavior that was confirmed by farmer survey responses, it is likely they continue to perform guarding behavior at night when pet dogs at farmsteads are typically indoors. In fact, when LGDs were detected on cameras at night, the LGDs were often performing defense or patrolling behaviors. However, because we see correlations between behaviors and dog presence and we did not control for the number of dogs in this study, further research to identify if a specific number of dogs is best is still needed.

Our fine-scale data suggest grizzly bears are avoiding farmsteads with LGDs. Notably, only five GPS-locations of bears were within 300 m of treatment farmsteads once the LGDs were placed, an 87.8 % reduction. Further, the total time GPS-collared bears spent near farmsteads dropped by approximately 95 % once LGDs were present, suggesting bears not only visited less frequently but also for less time. While this is seemingly robust evidence, we do note that different collared bears were monitored for different periods of time throughout the study. Thus, it could be the differences were in part because of differences in bear behavior; in fact, we saw a reduction in the time spent at both treatment and control farmsteads once LGDs were placed at treatment farmsteads. However, there are three lines of evidence that suggest LGDs may have caused this change and not the different behaviors of different grizzly bears. First, some LGDs spent time at or near the control farmsteads and this may have caused grizzly bears to also avoid these locations. Second, the decline in the total time and proportion of locations at control farmsteads was less than at treatment farmsteads. Third, the two bears with the most GPS locations within 300 m of farmsteads (i.e., 116 of 136 locations) were monitored for similar amounts of time before and once LGDs were placed. Changes in individual movement behavior of bears is notable because animals that learn to access human food resources are often implicated conflicts (Linnell et al., 1999) and it is easier to prevent learning from occurring than to alter a learned conflict behavior (Much et al., 2018). Since we obtained GPS-collar locations before and once LGDs were placed from five bears, including the two who visited farmsteads the most, our results suggest that grizzly bears learn to avoid farmsteads with LGDs they formerly visited. These fine-scale shifts that reduced the number and time spent visiting farmsteads are sufficient at preventing interactions between grizzly bears and humans at farmsteads, which eases concerns expressed by the farmers about human safety.

We only used data from GPS-collared bears located within 10 km of each farmstead to ensure the farmstead was part of the available habitat based on the scale at which bears use this type of landscape (Graham and Stenhouse, 2014; Servheen et al., 1995). We focused on the number of times grizzly bears were found within 300 m and 1000 m of farmsteads because 1000 m likely represented the footprint of the LGDs and 300 m likely represented the space in which a conflict with people and pets living on farmsteads would likely occur. At these distances, we found an impact of LGDs on grizzly bear presence but with different outcomes at the two distances. While the presence of an LGD reduced the proportion of locations a grizzly bear was detected within 300 m of treatment farmsteads relative to control farmsteads, this trend was not observed at the 1000 m distance. The lack of a statistical difference between treatment and control farmsteads at 1000 m after LGD placement could be because grizzly bears learned to avoid LGDs without avoiding the general area. This result suggests LGDs will not have broadscale effects. Instead, grizzly bears appear to retain natural movement behavior at a landscape scale but alter movement and behavior when encountering LGDs. Thus, LGDs are likely reducing conflicts without impacting bear behavior broadly.

Our results also suggest the 300 m scale was the most appropriate response variable for evaluating how LGDs may change bear behavior and space use. We had attempted to accurately quantify the footprint of the LGDs by using flight-initiation distance (FID; Ydenberg and Dill, 1986) tests to determine the farthest distance from farmsteads LGDs were responding to threats and used a human approach as the threat. However, the use of the FID test in the first year was ineffective because the LGD was too familiar with the person performing the FID and typically ran to greet the person before the test could begin. Because the LGDs did not perceive humans as a threat, we did not continue attempts at FIDs and therefore relied on the GPS-collar data from LGDs alone to quantify their potential footprint. Future studies on LGDs may want to consider novel ways to use FIDs, such as simulating predator presence.

Not every grizzly bear with access to farmsteads in this region was fitted with a GPS collar, so it was important we captured other metrics of visitation and behavior via camera traps. The camera trap data supported results from the GPS-collar data: fewer bears visited treatment farmsteads and the behavior of bears that still visited farmsteads shifted after LGD placement. When grizzly bears were detected at camera traps after LGD were placed, they were more likely to exhibit uncomfortable behaviors relative to behaviors observed at control farmsteads, suggesting the LGDs were effectively changing outcomes of farmstead visits. At night, LGDs were often observed on camera traps in defense behaviors associated with guarding. Together, these data suggest LGDs are effectively preventing grizzly bears from spending time feeding on grain and other agricultural products near homes. Altering grizzly bear behavior at this fine scale is likely reducing the chance of people and grizzly bears interacting, meaning LGDs are a promising nonlethal tool that is unlikely to affect bears in ways that would negatively impact populations.

Human perceptions, especially increased assurance for human safety, may be critical to conflict reduction and increased tolerance for recovering species since most human-wildlife conflict is more often human-human conflict (Dickman, 2010; Peterson et al., 2010; Redpath et al., 2015). Farmer surveys reported LGDs are effective at reducing interactions with grizzly bears at farmsteads. The LGDs were not reported to be aggressive towards familiar or unfamiliar people, most LGDs did not uncontrollably roam, and bonded to the family and other dogs at the farmstead. Only one LGD continuously strayed sufficiently far from the farmstead for us to construct a single-wire dog fence to create a radius of about 300 m around the farmstead. Once the fence was established, there were no other problems with that LGD. All the treatment farms said they would continue to use LGDs in the future and would recommend LGDs to other farmers. Two of the control farms also wanted LGDs by the end of the study, illustrating the importance of working directly with end-users to facilitate rapid adoption of successful techniques (Volski et al., 2021).

Interestingly, mesocarnivores were more frequently detected at treatment farms after LGD placement. The camera trap survey was designed to monitor grizzly bears and not for other carnivores and we do not know population trends of these species during our study; however, this result is worth mentioning because of concerns around LGDs harassing nontarget species (Allen and Hampton, 2020). There are several possible reasons for an increase in detections of mesocarnivores, including (1) increasing population size, (2) mesocarnivore release through the fine-scale exclusion of grizzly bears, similar to what was observed with LGDs in a transhumance system (Kinka et al., 2021), or (3) increased availability of dog food. These reasons are not mutually exclusive and do not preclude that LGDs could still prevent access to grain spillage by mesocarnivores if the LGDs were chasing and harassing them. While two out of four farmers self-reported that their LGDs chase wildlife, the increased detection of mesocarnivores suggests the wildlife that were chased by the LGDs were primarily grizzly bears and not other carnivore species.

In conclusion, our experiment shows that an ancient human technique is effective and increasingly relevant in modern society with recovering carnivore populations. LGDs have been used for thousands of years to protect livestock and people, yet the practice has been forgotten in many communities around the world. In North America, early historical records indicate dogs guarded camps of Native Americans and early explorers (Belden, 1870; Lewis, 1805). As carnivore populations declined, so did these ancient practices. Now rewilding is requiring relearning these often-forgotten techniques, but before now, to our knowledge no scientific tests have been conducted on the efficacy of LGD's for protecting farmsteads. LGDs are one more tool in the toolbox to help keep people safe while coexisting with recovering populations of apex predators.

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CRediT authorship contribution statement

Julie K. Young: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Wesley Sarmento:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Julie K. Young reports financial support was provided by Montana Fish Wildlife and Parks.

Data availability

The data that has been used is confidential.

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Data statement

Due to the sensitive nature of human privacy and GPS locations of an endangered species, participants were assured raw data would remain confidential and would not be shared.

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