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Drones outperform dogs for hazing bears: a comparison of carnivore aversive conditioning tools

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Human-wildlife conflict can result in harm to people and their livelihoods, and frequently ends in reduced tolerance for species and/or removal of animals. Resolving and preventing conflict is essential for conserving carnivore populations. Here I conducted a six-year study of the efficacy of non-lethal hazing tools to deter grizzly bears (*Ursus arctos*) away from people on the prairies of North-Central Montana. I tested a new technology, drones, and traditional methods of hazing bears including dogs, projectiles, and vehicular pursuit. These various hazing techniques were successful at stopping undesirable bear behaviors and caused a significant increase in avoidance behavior and distance to human infrastructure. Results from these 163 hazing events suggest aversive conditioning may have occurred over longer time scales as older bears required less hazing and hazing events decreased over each calendar year. Drones outperformed other hazing techniques where the odds of a pursuit of a bear being possible increased 127% relative to vehicular chasing due to accessibility issues. Relative to vehicular pursuit, dogs required high maintenance and had an 86% reduction in the odds a hazing event would be successful relative to vehicular pursuit. Grizzlies fled to locations that were farther from roads and human development. Hazing tools were effective for immediately resolving complaints and preventing further conflicts.

KEYWORDS

aversive conditioning, conflict prevention, human-wildlife coexistence, human-wildlife conflict, non-lethal, carnivore recovery, rewilding, UAV (unmanned aerial vehicle)

1 Introduction

Human-wildlife interactions occur worldwide and can have enormous positive and/or negative impact on people (Ekernas et al., 2017; Bhatia et al., 2020). Overlap of people and dangerous wildlife is of particular concern due to human safety, property damage, and the persecution of species that are increasingly valued and recognized as important to functioning ecosystems (Dickman, 2010). Real and perceived conflicts between humans and carnivores are a lose-lose situation where people are injured, killed, or livelihoods damaged while tolerance for predators decreases, relocations take place, or removals of offending individuals occur (Treves and Karanth, 2003). With human populations growing (Treves et al., 2006), we continue to press our interests farther into the habitats of large carnivores. Meanwhile, conservationists have been successful in the recovery of some predators, leading to these species increasing in numbers and expanding into human dominated landscapes (Ingeman et al., 2022). The concurrent increase in both people and carnivores in these situations has caused a significant challenge of finding a balance between the needs of people and wildlife. If carnivore populations are going to thrive then conservationists must meet the needs of people by finding new and improved ways to address safety and economic concerns (Venumière-Lefebvre et al., 2022).

Hazing carnivores away from people has almost certainly been a conflict prevention tactic used by people for thousands of years (Lambert and Berger, 2022). Hazing is the practice of chasing away wildlife to immediately alter behavior and/or spatial presence, often with the use of deterrents (Hopkins et al., 2010). The act of hazing often has three simultaneous goals of 1) stopping undesirable behavior, 2) immediately moving the animal away, and 3) a long-term modification of an animal's behavior, particularly to make it fear and avoid people and our settlements (i.e., aversive conditioning). Aversive conditioning may create a landscape of fear whereas animals avoid areas they perceive as high-risk (Cromsigt et al., 2013). To create this landscape of fear, prehistoric people likely hazed away dangerous animals with loud noises, fire, and primitive weaponry. Across the world, guard dog breeds were developed and employed to chase off predators from livestock and people (Young and Sarmento, 2024; Kinka and Young, 2019). In ancient times people probably used such non-lethal methods of wildlife deterrence frequently simply because there were more abundant carnivore populations.

During the past two centuries, many populations of carnivores had been significantly reduced or eliminated in most places dominated by people (Ripple et al., 2011). In the 1960s and 1970s attitudes towards predators began to fundamentally shift, which lead to a new interest in carnivores. This change in attitudes coincided with urbanization and thus the people that had a growing interest in predators were also the people that were least impacted by these species (Messmer, 2009). Those that stayed in rural landscapes often remained engaged in agricultural production and thus retained traditional views on carnivores (Volski et al., 2021). Traditional views often represent that humans have dominion over the land and thus predators should not be allowed to negatively impact people (Manfredo et al., 2017). Despite traditional concerns over carnivore recovery, many modern wildlife management policies (e.g., limited harvest quotas on mountain lions [*Puma concolor*] in some states) facilitated predator populations rebounding (Robinson et al., 2015).

With broader societal interest in conserving, instead of eliminating, carnivores came a renewed need to develop tools and methods to non-lethally deter predators from people to address apprehensions. Wildlife managers began employing scare tactics to push away predators to protect livestock and people (Table 1, Schirokauer and Boyd, 1998). New devices, such as bear spray, were invented, and proved to be highly effective at stopping attacks

TABLE 1 Results in chronological order from a literature search on Google Scholar for peer-reviewed publications from 1950-2023 with the following terms: aversive condition bear*, aversive condition carnivore* hazing bear*, hazing carnivore*, and drone hazing.

Year	Location	Species	Type	Successful	Main finding
2023	Italy	grey wolf	projectiles	yes	reduced livestock loss[1]
2021	Zimbabwe	lion	chasing	yes	more effective on males[2]
2021	Zimbabwe	lion	chasing	yes	reduced livestock loss[3]
2019	Zimbabwe	lion	chasing	no	consistency key to success[4]
2019	United States	puma	projectiles	no	too logistically difficult[5]
2019	United States	coyote	yelling, noise device	yes	more hazing has better results[6]
2017	Australia	dingo	air horn, water gun	mixed	water gun effective on young[7]
2017	United States	coyote	yelling, projectiles, chasing	no	no influence on human area use[8]
2010	United States	black bear	projectiles, pepper spray, chasing	mixed	most successful on non-food conditioned and older bears[9]
2004	United States	black bear	spray, projectiles, dogs	no	aversive conditioning not achieved[10]
2003	Europe	brown bear	projectiles, fireworks	mixed	sample size too small[11]
2000	Multiple	polar bear	projectiles	yes	99% of bears moved away[12]
1994	United States	brown bear	projectiles	yes	92% of bears left camps[13]
1992	United States	black bear	projectiles	yes	92% of bears left town[14]
1992	Russia	brown bear	dogs	yes	Use of several dogs most effective[15]

[1] (Zanni et al., 2023), [2] (Petracca et al., 2021), [3] (Sibanda et al., 2021), [4] (Petracca et al., 2019), [5] (Alldredge et al., 2019), [6] (Young et al., 2019), [7] (Appleby et al., 2017), [8] (Breck et al., 2017), [9] (Mazur, 2010), [10] (Beckmann et al., 2004), [11] (Rauer et al., 2003,), [12] (Smith et al., 2000), [13] (Schirokauer and Boyd, 1998), [14] (McCarthy and Seavoy, 1994), [15] (Gillin et al., 1997).

(Smith et al., 2008). Companies began to manufacture various projectiles to frighten wildlife such as cracker shells and rubber projectiles (Lackey et al., 2018). Managers also looked to the past to bring back old methods, such as dogs (Gillin et al., 1997). Many of these techniques are widely used and touted today, yet there is not a lot of empirical evidence comparing the efficacy of various hazing methods (Spencer et al., 2007; Clark et al., 2002). Additionally, since the invention of bear spray development in new technology to deter dangerous animals has been limited. For example, unmanned aerial vehicles (UAVs), or drones, have been available to the public for over a decade now, yet this new technology has not yet been tested as a possible hazing tool despite an ever increasing need to deter carnivores.

Grizzly bears (*Ursus arctos*) in the contiguous United States have been protected as threatened under the Endangered Species Act since 1975. Since that time their populations have rebounded significantly and are now expanding out of their predominantly mountainous public land recovery zones. As such grizzlies are increasingly occupying private lands on the prairie, which are dominated by people and agricultural production, namely livestock and grain crops (Sarmento and Carney, 2017). The growing presence of grizzly bears in North-Central Montana has led to concerns from local people for their safety and livelihoods (Nesbitt et al., 2023; Costello et al., 2020). In response to the growing concern over grizzly presence, additional bear management staff and resources were allocated to the area. To help meet the requests of the local communities the new bear management staff initiated a hazing program with the goals of 1) moving bears away from people and, 2) aversively conditioning bears to human presence and infrastructure. After conducting the hazing program for six years I wanted to understand how effective tools were at deterring grizzlies. Here I conduct tests of widely implemented hazing techniques as well as a novel tool, an Unmanned Aerial Vehicle (UAV or drone), at deterring grizzly bears away from people on the prairies of North-Central Montana. Drones have recently become widely available and capable of professional level tasks; thus, this emerging technology represents a new frontier in need of testing *in situ* on species in conservation need.

2 Materials and methods

2.1 Study area

I conducted this hazing study on the northern glaciated prairie ecoregion of North-Central Montana where grizzly bears are expanding east of the Rocky Mountain front onto private lands (Figure 1). The bears here are all a part of the Northern Continental Divide Ecosystem population which is over 1,000 individuals (Sells et al., 2023). The recovery zone for this bear population includes the Bob Marshall Wilderness Complex and Glacier National Park. Grizzly bears in this study area were subject to a continuum of bear management practices ranging from low level conflict prevention efforts such as guard dogs and scare devices, to more heavy-handed actions such relocation and lethal removal when warranted (Sarmento, 2024). The semi-arid prairie area where this study was performed is approximately 28,116 km^2 in size with an elevation range of 792-1,525 m. The landcover is primarily grasslands typical of the northern Great Plains, with abundant croplands and wooded riparian areas along the Teton, Sun, and Marias rivers. Pertinent plants surrounding these rivers are

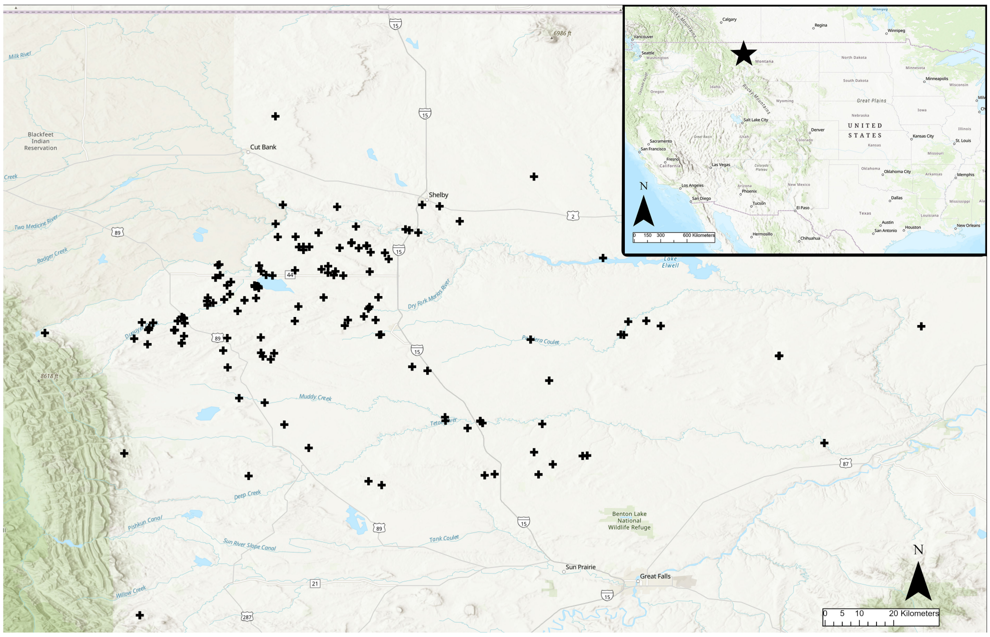

FIGURE 1
Map of North-Central Montana, USA study area showing locations where hazing events occurred from July 2017 to July 2023. Inset map of western USA to show larger geographical context.

dominated by cottonwood trees (*Populus* spp.), chokecherry (*Prunus virginiana*), serviceberry (*Amelanchier* spp.), and buffaloberry (*Shepherdia* spp.). Major crops include lentils, chickpeas, sunflower, flax, and various species of wheat. There are several small villages with less than 300 people and a few towns with less than 3,000 people. Livelihoods are primarily agricultural production of livestock or crops, and most of these producers live rurally on their farms or ranches. The majority of large mammalian wild fauna consists of whitetail deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), pronghorn (*Antilocapra americana*), and coyotes (*Canis latrans*), with lower numbers of wolves (*Canis lupus*), and black bears (*Ursus americanus*).

2.2 Data collection

From July 2017 to July 2023 the Montana, Fish, Wildlife and Parks Conrad bear management team and assignees initiated hazing events upon responding to public complaints of grizzly bears being observed near people or when the team was proactively patrolling the area looking for grizzly bears. This hazing program was conducted with the permission and ethical guidance from the United States Fish and Wildlife Service (annual permit) and Montana Fish, Wildlife and Parks. When a hazing event occurred, the following variables were recorded: the age and sex of the individual, bear identity, group size, time, date, initial behavior, food availability, distance of separation to the hazer, location, hazing tool, number of hazing events induvial had been exposed to, and the possibility of pursuit (Supplementary Appendix 1). Cubs-of-the-year only received two hazing events because this age group is not typically alone, and thus these samples were included with yearlings. Combining cubs-of-the-year with yearlings prevented any inferences on this age group. Behaviors included vigilant (head up, not laying down or moving), feeding (actively taking bites of food and chewing), bedded (laying completely down and not feeding), running (>2.0 m/s^{-1}), walking (<2.0 m/s^{-1}), nursing (female providing milk to young), drinking (consuming water), swimming, and predatory behavior where bears were pursuing prey (Supplementary Appendix 2). These behaviors were then classified as either afraid or unafraid. Food availability near the initial location of the bear was recorded to test if higher quality attractants lead to differences in the outcome of hazing events. Food categories included grain, meat (e.g., livestock, road killed wild ungulates), and natural attractants (e.g., berries and grasses). To avoid pseudoreplication of individuals in a group, only the largest individual was sampled (i.e., only data from the adult female was recorded if she had young with her). Bear identity was possible for some individuals through unique pelage markings, unique ear tag combinations, and/or GPS collars (Telonics model # TGW-4577-4) following approved methods from Montana's Animal Use and Care Committee (Montana Fish Wildlife and Parks, 2004). Some bears were unidentifiable and were recorded as such. Location and distance of separation were estimated using an aerial map (OnX Maps Model Hunt) on a smartphone (Samsung Model Galaxy S7). People involved in hazing determined the safest and most acceptable direction to chase the bear (e.g., away from houses, people, highways, or livestock). Landowner permission was always obtained before entering private lands and neighboring landowners were notified when hazing actions occurred. We sought randomization of hazing methods to follow strong experimental design principles. Field conditions, however, often required deviation from this randomization ideal, which was similar to other hazing studies (Mazur, 2010). The method of hazing that was selected was sometimes based on available equipment and safety considerations. For example, I could not safely shoot firearms in town or when the wildfire danger was high. Additionally, all people involved in bear deterrence did not have access to every hazing tool (e.g., only I had a drone). The suite of tools and techniques included vehicular pursuit, which sometimes included honking of the horn as an additional auditory stimulus. All the vehicles used were large pick-up trucks with four-wheel drive, which allowed for off-road use when appropriate. Pump action shotgun (Remington model 870) delivered projectiles were used and included cracker shells and rubber slugs (Margo Supplies; https://margosupplies.com/). Projectiles were generally not shot directly at bears due to a history of such less-lethal rounds causing death when used improperly. Cracker shells were always shot above target individuals, while rubber slugs were usually shot into brush near animals or at the ground near animals. All shotgun projectiles emitted a shot-like sound immediately when fired. Conversely, paintballs were delivered directly at bears, avoiding the face, from paintball guns (Tippman Cronus). Paintball guns emitted a muffled shot sound when fired and were used with ordinary paintballs typically deployed recreationally on people. One redline Airedale dog was purchased and another was donated from Rock Creek Airedales (Pawhuska, Oklahoma) for the purpose of hazing bears. This breed of dog was chosen because the agricultural producers in the area favor this variety for chasing predators and conservation efforts garner better outcomes when they are developed with the community (Sarmento and Reading, 2016; Young et al., 2015). The Airedales were chosen from a breeder that had a line of dogs known for engaging dangerous wildlife (e.g., feral pigs [*Sus scrofa*]), and were acquired at two years old so they would be old enough to chase bears and properly socialized. The dogs were given additional training by the author and controlled using electronic collars (Garmin Model Alpha Tracker). Finally, drones equipped with a thermal camera (Autel Model Evo 2) were used to haze bears. These drones were capable of 30 minutes of flight with a 1 km range, when there was a clear line of sight. Bear response to hazing actions was recorded including behavior immediately after the hazing event, number of hazing events the individual had been exposed to, and the location the individual fled. Whether or not pursuing the bear was possible was also recorded. Possibility of pursuit was defined as staff being able to chase a bear for ten minutes without impediment (e.g., canals, fences, and other physical barriers). Bears were chased to more acceptable locations for bears which were considered places that were away from people, livestock and human infrastructure and included more natural areas such as creeks and coulees (Nesbitt et al., 2023; Costello et al., 2020). I observed bears for up to an hour after the initiation of hazing events. A successful hazing event was defined as bear moving more than 200 m away, which is double the minimum distance people are allowed to be from grizzly bears in United States of

America National Parks. Longer term monitoring of bears was not possible because most bears were not marked or collared.

To understand where bears fled, landscape covariates were gathered into ArcMap 10 Geographic Information System (ESRI) from existing databases (Supplementary Appendix 3). A 2018 landcover map was obtained from the Montana Natural Heritage program with a 30 m resolution. From the landcover database I created a map of human development areas by extracting cover classes including: high intensity residential, commercial/industrial, low intensity residential, and developed open space. Next, using the same landcover database, I made a hiding cover map by extracting categories that bears were known to shelter in, including all the forest, woodland, shrub, and riparian cover classes. A roads map was obtained from the Montana Department of Transportation. A map of streams, rivers, canals, and other waterways was obtained from Pacific Northwest River Reach Files. Then, using the Euclidean Distance spatial analyst tool in ArcMap, I created "distance to" variables including roads, developed areas, waterways, and cover covariates using a 10 m cell size. Slope variability was calculated by subtracting the maximum slope from the minimum within a digital elevation model. Bear locations before and after hazing event were then intersected with these landscape covariates. Before locations were where bears were located when first detected by management staff, while after locations were the places where bears fled. To understand where bears fled relative to where they did not flee, I used the "create random points" function in ArcMap 10 to generate five unused, but available random points within a 1,086 m (average flight distance) radius buffer around starting locations. I used the average flight distance to generate these points, because farther distances might not always be available (e.g., a young bear might not be able to flee as far as an older bear). I chose five unused locations to minimize contamination which could bias selection towards the actual flight location (Sarmento and Berger, 2020). These random points were also intersected with the other landscape covariates.

2.3 Data analyses

Using the statistical program R (Team R Core, 2023), I created five models to understand grizzly bear hazing. First, I created a hazing success model (Model A) and pursuit possible model (Model B) - both using the glm function with a binomial family and logit link to test what variables influenced these outcomes (Supplementary Appendix 4). Then, I ran a separate temporal model using logistic regression with a binomial family and logit link to test possible effects of year, season, and time of day on hazing success (Model C). Next, I tested if there were differences in the amount of hazing across seasons using a McNemar's Chi-squared test with continuity correction (Venumière-Lefebvre et al., 2022). Using the same Chi-squared test, I examined if bears displayed more fearful behaviors after hazing compared to before. After that, I used linear models to test what variables influenced the number of times a bear was hazed (Model D). Finally, I ran a resource selection analysis (Model E) to test where bears fled by performing a conditional logistic regression with the event as the unique strata and using the glm function with a binomial family and logit link. To test if bear flight locations were different from pre-hazing locations, I used a nonparametric Wilcoxon T-test comparing before and after distances to roads, development, and waterways.

All models were tested for independence of variables by 1) a variance inflation factor of less than ten, 2) correlation between variables of less than 0.6, and 3) whether coefficient estimates changed more than 20% with the removal of covariates (Bursac et al., 2008; Hosmer et al., 2013). Collinearity was estimated using a correlation matrix. Variables that were not independent were tested in separate models to assess relative performance. Diagnostic plots (residuals, Cooks distance) were examined to identify potential issues such as non-linearity, non-normality, heteroscedasticity and that outliers were not unjustifiably influencing statistical outputs. All global models (Supplementary Appendix 5) then underwent backward stepwise selection to independently remove the most insignificant variable (largest P-value) one at a time until only significant covariates remained to produce a top model (a-priori P-value significance level less than 0.05). Z-Scores or T-Scores are reported depending on the model to demonstrate relative effect size.

2.4 Qualitative comparison

To place my results in the context of other studies I conducted a systematic literature search using Google Scholar for peer-reviewed articles from 1950-2023. I searched for the following terms: aversive condition bear*, aversive condition carnivore* hazing bear*, hazing carnivore*, and drone hazing. Only papers relevant to hazing, defined as a human administering a deterrent to immediately deter a bear and/or to modify a bear's undesirable behavior, were included in the final database (Hopkins et al., 2010). Additionally, I wanted to compare the available hazing tools further with characteristics that I could not adequately quantify but are pertinent to bear management staff. Thus, together with three of my bear management staff we qualitatively compared each tool using nine factors with specific criteria (Supplementary Appendix 6). First, we assessed characteristics of each tool related to their safety, precision, maneuverability, and the range tools could be used. Qualitatively we assessed the efficacy of each tool for moving stubborn bears that were holding their ground. Next, we evaluated the start-up costs and maintenance time of each hazing tool. We also considered the amount of skill each tool required staff to operate, and the potential for unintended consequences, such as starting wildfires. Finally, we qualitatively compared how the tools were perceived by the local communities and how they operated in inclement weather.

3 Results

A total of 163 hazing events were recorded, which comprised 35 drone, 52 vehicle, 30 dog, and 46 projectile occurrences. Out of all these hazing events, 77 occurred on adults, 47 on subadults, 37 on yearlings, and only two on cubs-of-the-year (combined with yearling class in analyses). These aversive conditioning trials happened on 40 males, 61 females, while the sex of 62 individuals was unknown. Hazing was conducted on 55 known individuals, and 108 events occurred on unidentifiable bears. No known injuries or deaths occurred with any of the bears or people during any of these hazing events. 74% of hazing events occurred in May and June, and then tapered off as the year progressed, with 22% in the summer, and 4% in the autumn (Supplementary Appendix 7). There were significantly more (McNemar's chi-squared = 44.16, D.F. = 1, p-value = <0.05) hazing events during the spring (April-June) compared to summer (July-September). Spring also had more hazing events relative to autumn, which I defined as October to December (McNemar's chi-squared = 98.772, D.F. = 1, p-value < 0.05). Hazing success, however, was not influenced by year, month, or time of day (Table 2).

Hazing success was significantly influenced by the method used, where dogs (57% success) were less effective relative to vehicles and drones (Figure 2, Table 3). Drones had the highest success (91%), but not significantly more than vehicular pursuit (85% success) or projectiles (74% success) because confidence intervals overlapped. The age of the grizzly bear also was an important factor in hazing success. Relative to adults, younger bears needed more aversive conditioning (Table 4). Possibility of pursuit of bears was more possible with the use of drone compared to any other tool, while distance to road and bear age also influenced pursuit opportunity (Table 5). Bears were significantly more likely to display fearful behaviors after hazing relative to before (McNemar's chi-squared= 132.01, D.F. = 1, P= <0.05). Behaviors before hazing included: feeding (53), walking (55), bedded (38), vigilant (9), predatory (4), drinking (2), swimming (1), and nursing (1). Behaviors after hazing included running (133), bedded (10), vigilant (9), feeding (4), walking (4), and swimming (2).

Apart from quantitative divergence in hazing methods, there were several qualitative differences between the tools (Table 6). Staff considered drones safer, more maneuverable, and more precise. Dogs required a lot of training and maintenance time, in addition to having low precision. Trucks and projectiles fell within the middle of the qualitative comparison of the tools. For the systematic literature search, I manually screened 2,910 peer-reviewed publications for relevance to hazing carnivores. Out of those publications I determined 15 to be pertinent to aversive conditioning of predators (Table 1). Eight of the studies (53%)

TABLE 2 Beta coefficient estimates from a logistic regression model testing the influence of season, time period, and year on hazing success of grizzly bears in North-Central Montana, USA from July 2017 to July 2023.

Covariates	β	S.E.	Z-score	P-Value
(Intercept)	-129.69	251.43	-0.52	0.61
Year	0.06	0.12	0.52	0.60
Spring	0.42	0.86	0.49	0.62
Summer	1.05	1.01	1.04	0.30
Evening	-0.52	0.58	-0.91	0.37
Morning	0.04	0.59	0.07	0.95

Autumn season and daytime are set as baselines. A successful hazing event was defined as a bear moving 200 m or more away.

found hazing to be successful. Three studies (20%) reported mixed results, while an additional four studies found hazing not successful.

Grizzly bears fled to places that were significantly different from where they were initially located. Bear locations were significantly (w = 9884, P = <0.01) farther from human development (882.28 m [S.E. = 87.01] before hazing on average compared to 1193.42 m on average after hazing [S.E. = 77.03]). Additionally, distance to roads increased significantly (w = 8186.5, P = <0.01) from before (average= 558.09 m [S.E. = 49.14]) to after (average= 945.83 [S.E. = 50.73]). Bears were 497.99 m (S.E. = 40.93) from water on average before hazing compared to 440.09 m (S.E. = 46. 98) from water after hazing (W = 15234, P = 0.02). Grizzlies specifically selected for flight locations that were farther from roads and closer to water (Figure 3, Table 7).

4 Discussion

4.1 Overview

Hazing has been attempted on large carnivores worldwide to immediately move dangerous animals away from people and to aversive condition them to humans over longer time scales. Our hazing efforts on grizzly bears were largely successful, and these results suggest aversive conditioning to people and human infrastructure did occur, although I could not rule out other possibilities. The need for hazing events decreased over the course of each year, which could be attributed to both aversive conditioning and bear biology. May and June, when most hazing occurs, coincides with their breeding season when bears are highly active and young are being kicked-off their mothers. Naïve yearlings and subadults (two-three-year-old bears) often do not know to stay away from people. The odds of a bear being involved with additional hazing events increased 2.27 times for yearlings relative to adults. Young bears and females with cubs-of-the-year appeared to conform to ideal despotic distribution where they were residing near people to avoid dominate infanticidal adult male bears that occupy better habitat away from people (Beckmann and Berger, 2003). Hazing may cause females with young to expose their young more to male bears, however, the risk of natural infanticide is more acceptable than bears causing conflicts, which can result in adult females being euthanized and thus orphaning young. By July, the bear breeding season is over and natural berry crops typically start to draw individuals away from people. Despite these biological drivers of hazing reduction after June, the evidence still suggests that aversive conditioning is a factor explaining this pattern.

Hazing appeared to have a long-term behavioral and spatial modification (aversive conditioning) on bears, which led to individuals avoiding people and human infrastructure. To begin, I observed the same patterns of reductions in hazing efforts after June during poor berry production years (e.g. drought of 2022), and year was not an important predicter of hazing success. Additionally, shrubs typically lose their berries after the first hard frost in September and bears enter hyperphagia during the fall, thus a high demand for limited food, yet our hazing events did not increase during the autumn months suggesting bears learned to avoid people through aversive conditioning from earlier in the year.

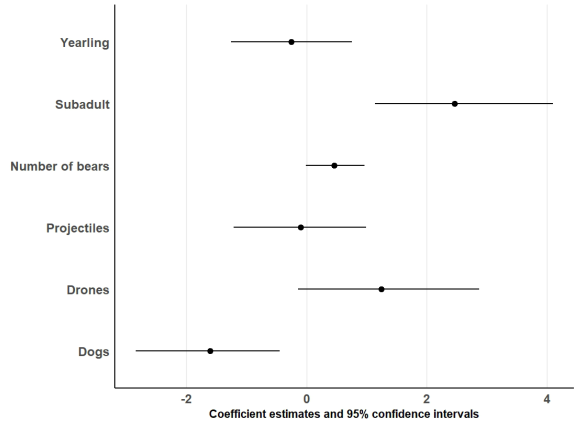

FIGURE 2
Beta coefficient estimates from top logistic regression model testing the success of hazing events on grizzly bears in North-Central Montana, USA from July 2017 to July 2023. A successful hazing event was defined as bear at least 200 m away. Error bars represent 95% confidence intervals. Baselines include adult bears and vehicular pursuit hazing type.

Bear populations in temperate areas often show a sharp increase in the number of human-bear conflicts during the fall period when bears are putting on weight before hibernation (Zarzo-Arias et al., 2021). Our collar data and observations from marked bears confirm bears were avoiding people during the autumn, although sample size of individuals with GPS trackers was too low to include. Finally, younger bears (yearlings and subadults) were involved in significantly more hazing events compared to adults suggesting that bears learned to avoid people as they aged but may also be attributed to overall life experiences with people. Some yearling bears required over five hazing events while the most any adult was hazed was three times.

In terms of general success, these results aligned well with other studies on other species worldwide. Hazing success was not influenced by season, year, or time of day. Thus, the timing of hazing events didn't appear to be important. Hazing was just as effective in the breeding season as it was during the autumn season when bears are driven to find more food before hibernation. Even during spring season when food was limited hazing success was the same as during the summer season when berries and other natural foods were abundant. Furthermore, the type of food bears were using before a hazing events didn't appear to have an influence on hazing success, suggesting that the immediate risk of people and our tools outweighed any benefit they were obtaining from anthropogenic attractants such as grain, garbage, or livestock. Among all the multitude of possible responses to bear complaints, various studies have suggested aversive conditioning to be an effective approach to resolving issues, although securing attractants is also essential (Crevier et al., 2021; Baruch-Mordo

TABLE 3 Beta coefficient estimates from top logistic regression model testing the success of hazing events on grizzly bears in North-Central Montana, USA from July 2017 to July 2023.

Covariates	β	SE	Z-Score	P-Value
(Intercept)	0.23	0.69	0.34	0.74
Dogs	-1.61	0.60	-2.66	0.01
Drone	1.24	0.75	1.66	0.10
Projectiles	-0.11	0.56	-0.19	0.85
Subadult	2.46	0.74	3.33	< 0.01
Yearling	-0.26	0.51	-0.51	0.61
Number of bears	0.45	0.25	1.81	0.07

A successful hazing event was defined as bear at least 200 m away. Baselines include adult bears and vehicular pursuit hazing type.

TABLE 4 Beta coefficient estimates from top linear model explaining how many times individual grizzly bears were hazed in North-Central Montana, USA from July 2017 to July 2023.

Covariates	β	SE	T-Score	P-Value
(Intercept)	1.25	0.15	8.50	< 0.01
Subadult	0.71	0.24	2.96	< 0.01
Yearling	0.82	0.25	3.23	< 0.01

Adult bears are set as baseline.

TABLE 5 Beta coefficient estimates from the top logistic regression model testing whether a grizzly bear could be pursued during hazing events in North-Central Montana, USA from July 2017 to July 2023.

Covariates	β	SE	Z-Score	P-Value
(Intercept)	-3.05	0.69	-4.40	< 0.01
Dogs	-0.14	0.70	-0.20	0.84
Drones	4.85	0.89	5.44	< 0.01
Projectiles	0.03	0.65	0.05	0.96
Distance to roads	0.00	0.00	2.18	0.03
Subadult	0.85	0.66	1.28	0.20
Yearling	1.58	0.68	2.32	0.02

Baselines include vehicular pursuit and adult bears. Possibility of pursuit was defined as staff being able to chase a bear without impediment (e.g., canals, fences, and other physical barriers) for ten minutes.

TABLE 6 Qualitative comparison of different hazing methods tested on grizzly bears in North-Central Montana, USA from July 2017 to July 2023.

Factor	Vehicle	Projectiles	Dogs	Drone	Notes on limitations
safety	high	moderate	low	high	Risk of injury to dogs is high. Projectiles can unintentionally kill.
precision	moderate	low	low	high	Difficult to control where bears flee with dogs and projectiles. Dog detection limited.
range	high	low	high	high	Projectiles have limited range.
maneuverability	low	low	high	high	Trucks stopped by fences, private land, brush, waterways.
expense	high	low	moderate	moderate	Trucks have high startup cost. Dogs require a lot of ongoing costs.
maintenance time	moderate	low	high	low	Dogs take daily maintenance.
collateral damage	moderate	moderate	moderate	low	Trucks rip up fields. Projectiles can cause fire. Dog can cause chase other animals.
skill requirement	low	low	high	moderate	Dogs take a significant amount of training to handle properly.
moving bayed up bear	low	high	high	moderate	Trucks and the drone are often not effective at moving bear out of thick brush.
local support	high	high	high	high	People supportive of all hazing efforts. Particularly like the dogs
inclement weather	moderate	high	high	low	Trucks stopped by mud, deep snow. Drones stopped by wind, precipitation.

Green shading represents more favorable aspects of a hazing tool, while orange represents less a less favorable aspect. Yellow indicates moderate favorability of a hazing tool.

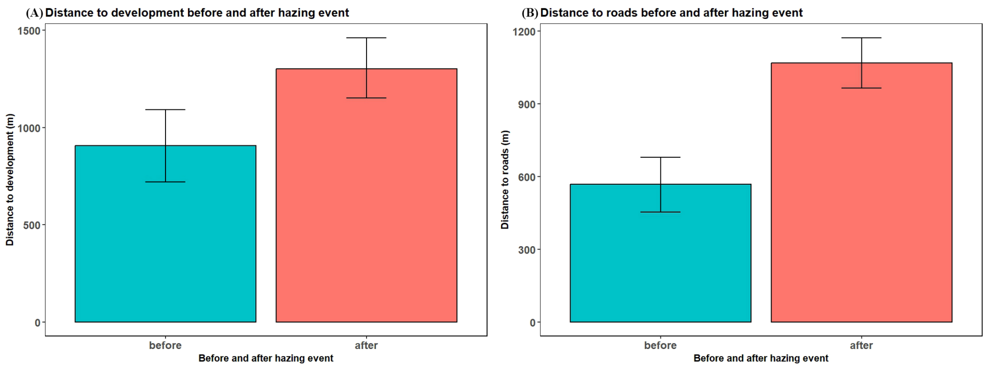

FIGURE 3
Bar graphs representing the distance of bears to **(A)** human development and **(B)** roads before and after hazing events in North-Central Montana, USA from July 2017 to July 2023. Error bars represent standard errors.

et al., 2013; Marley et al., 2019). Removing food attractants, however, is an often-difficult request to residents in areas where carnivores are recovering, but tolerance for those species is low. Additionally, many farm attractants in my study were not easy to secure, for example thousands of pounds of spilled wheat grain (Sarmento, 2024). Conversely, hazing appears to be a more acceptable approach for community members to keep bears away, although such social data is lacking. In all, there is a growing body of research suggesting that hazing can be an effective wildlife conservation and management tool.

TABLE 7 Beta coefficient estimates from the top conditional logistic regression model testing where grizzly bears fled after hazing events relative to five random, but available locations in North-Central Montana, USA from July 2017 to July 2023.

Covariates	β	SE	Z-Score	P-Value
Distance to roads	1.55	0.21	7.37	< 0.05
Distance to water	-0.66	0.23	-2.89	< 0.05
Elevation	0.00	0.00	-2.04	< 0.05

In our system, hazing was effective at immediately deterring bears from unwanted behaviors (e.g., chasing livestock) and unwanted places (e.g., near homes). Before hazing events occurred 90% of bear behaviors were either bedding, feeding, or walking. While hazing caused 81% of bears to engage in running behavior after the aversive conditioning event concluded. This negative risk stimulus where bears ran away appeared to result in aversive conditioning where, over time, bears learned to avoid people and human infrastructure. Most other research has also found that adult individuals are more responsive to aversive conditioning (Petracca et al., 2019; Mazur, 2010). Although one study on dingoes in Australia found that young animals were more responsive to treatments, however, sample size was extremely small (Appleby et al., 2017). Our results also suggest that consistency led to successful aversive conditioning, similar to what has been found for coyotes and lions (Young et al., 2019; Petracca et al., 2019).

4.2 Drones

Unmanned aerial vehicles (drones) successfully deterred bears away from people in 91% of events, although drones were not significantly better than projectiles or vehicles due to overlapping confidence intervals. The small sample size of this study likely led to larger variance, while future studies could increase statistical power by conducting more hazing events and testing tools across a larger spatial scale. It would be particularly interesting to know if these same patterns hold up in a more forested environment where drones might not be as maneuverable. Hazing success was highest with drones, which is likely due, in part, to the increased ability to pursue bears on the prairie. With drones I was able to pursue grizzlies across canals, muddy fields, seeded cropland, and fence lines which would have hindered our efforts with other techniques. Furthermore, drones were incredibly useful at locating bears, although I did not collect data on this metric. By flying high in the sky, I could quickly detect bears in the area, particularly while using the thermal camera during cooler weather (Figure 4). On several occasions, I was able to find bears in brush that I would not have been able to find otherwise.

Drones exceeded other tools on several qualitative metrics, which are useful in comparing the tools in a way that is difficult to capture quantitively. Drones were highly maneuverable and capable of precisely moving a bear exactly where I wanted the individual to go. Several times bears attempted to dodge the drone and run in an errant direction, however, the speed and dexterity of the drone allowed for quick corrective actions to alter bear escape paths to be more suitable. For example, I was able to haze bears directly between houses to get them farther away from people. Furthermore, drones were extraordinarily safe as the pilot can control the drone from a secure location. Overall, maintenance was low for drones and required little skill to learn, however, pilots are required to obtain a Federal Aviation Administration flying certification. The one category drones performed poorly in was operability in inclement weather, where high wind (>40 KPH) and precipitation prevented flights.

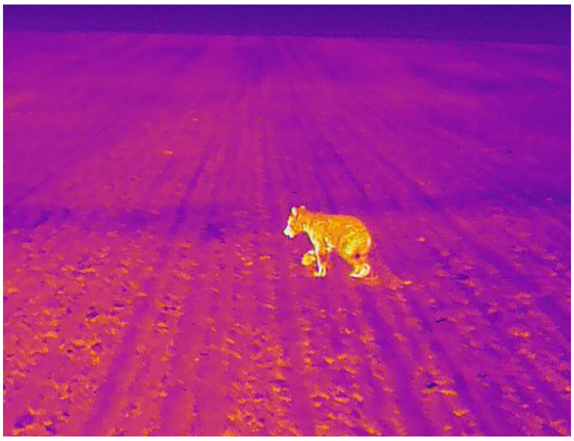

FIGURE 4
Thermal image of a yearling grizzly bear being hazed away from human areas on the prairie using a drone.

Beyond bad weather these results show that currently available drones are an effective tool for hazing an apex predator. Past research has shown that drones increase stress response in black bears, by elevating heart rate by as much as 123 beats per minute over baseline (Ditmer et al., 2015). The same study did not find a behavioral response to flights over black bears, however, the researchers were merely loitering above bears and not attempting to haze the animals. The evidence is clear that bears fear drones, but the mechanisms why remain poorly understood. Does the humming of a flying drone sound like a swarm of angry bees, or is the novelty of a flying object enough to scare bears? Or perhaps egg eating bears have been conditioned by bombarding adult birds protecting nests? Despite our lack of mechanistic understanding, it is obvious that the use of drones in wildlife management is a huge frontier with significant applications for wildlife conservation that we are just beginning to explore.

4.3 Dogs

Dogs had an 86% reduction in the odds a hazing event would be successful relative to vehicular pursuit – a low efficacy which could be attributed to several causes. Most importantly, the dogs had difficulty in detecting bears from farther distances. On average I initiated a hazing event at about 204 m away from a bear. At this distance and beyond the dogs were usually unable to detect bears. In addition, the dogs regularly engaged whatever species they detected first. Each dog went after porcupines (*Erethizon dorsatum*) on three separate occasions. Out of the six total porcupine incidents, four required veterinarian care. Once an Airedale was seriously injured by a porcupine, bear management activities had to cease to properly care for the dog. On one occasion I released the dogs on a grizzly that was only 51 m away, but the dogs failed to detect the bear and instead engaged with a feral cat that was closer. To some degree dogs can be trained not to go after non-focal species, however, dogs cannot be trained to detect targets at long distances as it is simply beyond their biological capacity to see that far, which may be an issue specific to the wide-open prairie environment where this research occurred.

My efforts may have been limited due to the breed or specific dogs obtained. I decided on Airedale dogs because the breed is highly favored by local agricultural producers for chasing predators and conservation outcomes are more successful when the community perspectives are considered. Some of the only positive comments I received from a handful of regularly irate constituents were regarding the dog hazing efforts. As such, the dogs seemed to act as ambassadors for the bear program and often diffused tension with upset individuals. I obtained two-year-old dogs because I wanted to be able to deploy them immediately and these dogs had been well socialized to children and other dogs. Liability is large concern for government agencies and thus I purposefully sought out dogs that I was confident would not harm people or farm animals. The dogs did exceptionally well with children and other dogs, however, the lack of early training with firearms may have predisposed them to fear loud noises. The Airedale dogs I received had experience pursuing feral hogs in Oklahoma, but that type of hunting does not involve firearms. These dogs were constantly afraid of firearms which also limited their efficacy as they would hide instead of seeking out bears. Thus, when using these dogs to haze, I had to forego carrying firearms, which increased risk for management staff.

There is little comparison to our study as there is scarce published peer-reviewed evidence on dog use for hazing carnivores despite it being a common tactic and widely promoted. One rigorous study performed with dogs at Lake Tahoe found that this method was not effective at aversive conditioning bears over one month (Beckmann et al., 2004). Another study was conducted in Russia, however, it lacked any quantitative results (Gillin et al., 1997). The most common breed used for chasing bears are the Karelian bear dogs. I initially contacted a private organization about contracting their Karelian dog hazing service, however, the cost was prohibitive at $5,700/day with a suggested initial work period of two weeks which would have cost $79,800.

Overall, our study results suggest that dogs are a less effective and riskier tactic for hazing grizzly bears. Beyond porcupines, the dogs themselves are in danger of being attacked by bears, which if it occurred would reflect poorly on a public program where a high level of animal welfare is expected. Furthermore, these dogs were not precise in where they chased bears. Once on a bear, the dogs simply chased the bear, while handlers were unable to alter the direction at which the dogs were running. Lack of precision increases the possibility of dogs running grizzlies to less desirable locations (e.g., back into town).

In general, these results suggest that dogs are not the best tool for management staff to haze bears. Apart from efficacy and safety issues, the dogs required significantly more maintenance and care than any other tool. The maintenance demands relative to their performance did not justify the program. Better dogs or training could change the cost-benefit equation. Finally, dogs used in a hazing program should not be confused with dogs used as guardians (Kinka and Young, 2019). Guardian dogs (e.g. Kangal, Pyrenes, etc.) protect livestock or homes, which is a different technique, and thus their efficacy is out of the scope of this study (Young and Sarmento, 2024).

4.4 Projectiles

The results from this study generally conform to other studies of hazing on bears with projectiles conducted around the globe. Projectiles have been used for decades with the first studies conducted in Alaska during the 1990s, which found high efficacy of keeping bears out of towns and camps (Schirokauer and Boyd, 1998; McCarthy and Seavoy, 1994). In the early 2000s more rigorous studies were undertaken on hazing bears with projectiles in the contiguous United States. The newer research, however, did not find the same level of success (Rauer et al., 2003; Beckmann et al., 2004; Mazur, 2010). One possible reason for the difference in results could be due to the location of the studies. The newer studies were carried out in places with high-human density (e.g., Lake Tahoe and Sequoia National Park). It is likely that bears having frequent neutral, or positive (receiving a food reward), interactions with people in these more populated places, swamps out the amount of negative stimuli wildlife managers can apply. Although the projectiles immediately moved bears away, these studies did not find evidence for aversive conditioning. Thus, bears in high human use areas learn that people are more frequently associated with rewards than risk.

Differences in projectile efficacy may also be due to the highly variable level of negative stimulation that they cause, which ranges from extreme pain to auditory/visual disturbance. The most common projectiles are hand-thrown rocks, paintballs, and firearm delivered rubber rounds, beanbag rounds, and cracker-shells. Direct contact with an animal is a stronger negative stimulus compared to cracker-shells that explode mid-air. In my study, bears sometimes did not appear to associate the exploding sound of a cracker-shell in the in air with people or the need to flee. While there was no doubt where projectiles that made physical contact came from. Rocks and paintballs cause some discomfort, while rubber rounds are so solid and high velocity that they are potentially dangerous. I chose to group all projectiles into one category because my sample size was not large enough to separate. Future studies would benefit from a larger sample size of projectiles which would enable comparison across the range of projectile types. Some bear managers suggest using the most painful stimulus first to give bears the strongest negative association with people as quickly as possible.

Several studies have also tested various projectiles on other species besides ursids. Rubber rounds were found to be effective at reducing livestock loss from wolves in Italy (Zanni et al., 2023). One study attempted throwing rocks at coyotes in an urban environment, however, these projectiles did not alter coyote spatial use (Breck et al., 2017). In Australia, researchers used a water gun to haze a small number of dingoes, which repelled juveniles (Appleby et al., 2017). Bean bag rounds were shot at mountain lions in Colorado although the aversive condition effort did not result in long-term modification of unwanted behavior (Alldredge et al., 2019). Again, more urban situations appeared to cause a reduction in efficacy, which is perhaps due, in part, to inconsistent human-wildlife interactions. Some of the contrast between these studies is a result of different goals. Some researchers were seeking to merely haze carnivores to move them away immediately, while others were seeking long-term changes in animal behavior and space use (i.e., aversive conditioning). In most circumstances both goals are desirable. Other differences between studies are likely due to the wide variety of projectiles used.

All projectiles are important tools in the toolbox for conservation practitioners and wildlife managers, while some methods are not suitable for public use. Rocks, water guns, and paintballs are all generally harmless projectiles that can be used by most anyone with some common sense, and no training. By avoiding the face, and particularly the eyes, these tools can be safely used by the public and should be encouraged as consistency increases efficacy. Aversive conditioning works best when an individual receives the same negative stimuli from all people. Cracker shells are moderately safe and have been used by untrained people in the past as well. If people take the appropriate precautions, such as hearing and eye protection, then crackers shells can be used by untrained people if they do not fire the rounds directly at animals. The issue with cracker shells, however, is they frequently blow-up in the barrel or cause fires after a delayed explosion (i.e., blowing up on the ground instead of mid-air). Conversely, rubber rounds should only be used by trained professionals due to the lethal risk of these projectiles when not used with extreme caution. Sometimes invoking pain is the best method to conserve an individual as they learn to avoid humans, which prevents having to euthanize the animal due to it causing continuous problems. Cromsigt et al., 2013 recommended shooting young in front of mothers to elevate perceived risk, however, I avoided using projectiles on dependent young due to the potential of injuring small bears. Out of the 55 known individual bears hazed, I only had to euthanize one due to it becoming positively conditioned to human infrastructure and thus becoming an elevated human safety concern.

4.5 Pursuit

Vehicle pursuit was the most common scare tactic in this study because it didn't require any extra equipment and was exceptionally safe as people were protected inside metal exteriors. Bears responded well as vehicles are large and loud. Honking the vehicle horn was often conducted simultaneously to add additional negative stimulus. It is not surprising that vehicle pursuit scares off even the largest apex predator in the contiguous United States. Since the number of hazing events declined with the age of the bear and year did not influence hazing success, it appeared that vehicles and other tools did not lead to bears becoming habituated to the aversive conditioning stimulus. In places with higher human density such as national parks, however, the potential for bears to habituate to vehicles is likely much higher. National Parks also limit off-road travel which prevents managers from being able to pursue bears long enough to aversively condition them. I was also often limited to staying on roads because fields were inaccessible due to being wet or planted with crops. Furthermore, fences and waterways consistently impeded our ability to chase bears with vehicles. Where bears can be pursued with a vehicle it is important not to over-exhaust individuals, particularly on hot days. Hazing events limited to running bears hard for less than one kilometer or five minutes will prevent injuring bears from hyperthermia. If further distances are desired, then managers can move bears at slower speeds to avoid overexertion. Specific prescriptions, however, should not be mandated for professional wildlife managers as they need to adjust hazing activities to highly variable conflict situations.

Other studies have also found that chasing large carnivores can be effective deterrent which achieves aversive conditioning and reduces human-wildlife conflicts. A considerable body of research occurred on African lions (*Panthera leo*) in Zimbabwe, where local community members were hired to chase lions away from a no-tolerance exclusion zone where people resided (Petracca et al., 2019). These biologists found that hazing was most successful near the protected area and when lion prey was more available (Petracca et al., 2021). Consistent hazing starting early on in response to problem behavior was considered key for successful aversive conditioning. Adult males responded best to hazing and shifted their home ranges more into the protected area. This community-based hazing program led to a reduction in livestock loss and retribution killing of lions in response to conflict (Sibanda et al., 2021).

4.6 Conclusions

These results suggest that hazing is an often appropriate first action when responding to a complaint about an apex predator or for proactively keeping carnivores away from human-dominated areas. In my study area hazing grizzly bears was an effective resolution to many complaints and evidence suggests bears may have become aversively conditioned over time. Most of the bears I hazed did not need farther management action and learned to stay away from people over time. Every situation is different, however, thus hazing should not be mandated so that each conflict response can be uniquely crafted by the professionals on the ground. Studies from around the world illuminated patterns which led to more successful outcomes including hazing animals before problem behavior becomes strongly established and consistently applying aversive conditioning tools. Furthermore, hazing efficacy appears to be reduced in areas of high human density which is likely the result of frequent positive/neutral interactions with people. In my study no bears were harmed during hazing events, but undoubtedly bears likely had elevated stress levels. It was unknown how the various hazing methods influenced bear stress levels, but future research could address this gap in knowledge. The stress hazing causes bears outweighs the potential of grizzlies causing conflicts, which could result in relocation or euthanasia. Teaching bears to fear people and our infrastructure results in net benefits to grizzlies where they are better able to navigate a landscape of people and anthropogenic foods. Bears that avoid people not only stay out of conflict, but they are also probably less likely to be illegally poached, killed in self-defense, or hit on roads.

These results provide evidence that drones are an effective and safe predator deterrent, and I recommend that this tool be added to other carnivore hazing programs. Conversely, regulations should be developed to limit disturbance to grizzly bears from recreational or commercial drone use in acceptable grizzly bear habitat. Grizzlies should not be allowed to be disturbed by drones for filming purposes and should not be desensitized to this stimulus or else it may reduce the efficacy of this tool for hazing. Anecdotally, bears did not appear to react from the drone beyond 100 m, which is also the National Park Service minimum distance people must maintain from grizzlies, and thus this may be a good minimum distance to require for filming in the absence of more specific data. Further research could better determine what acceptable drone filming distance should be to prevent disturbance or habituation for bears that do not need aversive conditioning (e.g. bears away from people).

Drones are an exciting new and effective technology that has been thus far underutilized by conservation practitioners, while the future applications of this tool present a huge possibility of facilitating human coexistence with dangerous animals. Looking forward, drones could be specifically modified for a focus on hazing. For example, drones could be engineered to remotely deliver a bear spray deterrent, which would help move stubborn bears that are bayed up in brush near people. Bear spray would likely need to be dropped from drones instead of deployed directly from the unit as the wind inference from the rotors could cause the capsaicin to spread across the drone itself. Bear spray delivered from dropped canisters similar to tear gas could be an effective approach. Drones with additional sound stimulus, such as humans yelling or dogs barking, could also be incorporated to increase efficacy. Research and exploration of regulatory hurdles would be needed to integrate other deterrents with drones. Another possibility would be to design a drone specifically for home protection, where Artificial Intelligence identifies dangerous wildlife and then autonomously chases off the individuals with a drone to preset safe and acceptable locations. Already cameras have been engineered to identify bears, but linking image recognition technology with drones has yet to be explored for human-wildlife conflict prevention. Regulations preventing self-flying drones are the biggest challenge preventing innovation, and thus exemptions would need to be sought to develop such a system. Researchers would need to work directly with the technology sector to develop such tools directed at influencing the behavioral ecology of wildlife. An automated drone home protection system could replace the need for guardian dogs around the home or for livestock protection as these dogs also have high maintenance costs. Drones could also be programed to seek out collared bears that were caught in conflict situations. Without a doubt the possibilities of drone technology in wildlife conflict prevention are endless, while this study is a critical step in advancing the technology in this field.

Data availability statement

Data includes sensitive information on an endangered species as well as sensitive information on private landowner's property. Requests to access the datasets should be directed to WS, wmsarmento@gmail.com.

Ethics statement

The animal study was approved by Montana Fish Wildlife and Parks. The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

WS: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2024.1478450/full#supplementary-material

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