Aversive conditioning of grizzly bears produces high probabilities of retreat from human-bear conflict locations

by

Claire Edwards

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in

Ecology

Department of Biological Sciences
University of Alberta

ABSTRACT

Parks and protected areas provide important refugia for source populations of threatened grizzly bears in Alberta, where high human-use and recreation can cause human-bear conflict. Many jurisdictions in Alberta and beyond use hazing and aversive conditioning (hereafter AC) programs to deter bears from potential conflict, but there are few established standards with which to design and evaluate these programs. I examined data from an AC program in Kananaskis Country that occurred from 2000 to 2019 to (a) describe and summarize the scope of the program, (b) quantify the type and frequency of tools used to treat bears and (c) evaluate correlates of conditioning success, measured as retreat by bears from locations of potential conflict as conditioning technicians arrived, immediately following each action, and after the conditioning event (consisting of a series of 1-5 conditioning actions) was completed. AC events employed four conditioning tool types, each with two or three deployment methods that included noise (vehicle, human, Karelian bear dog), approach (vehicle, human), projectiles (no-contact, contact) and pursuit (human only, human and Karelian bear dog). In addition to conditioning variables, I evaluated several demographic and contextual variables and accounted for the identity of individual bears.

In the 20 years of data I analyzed, technicians applied AC to 48 marked bears and an unknown number of unmarked bears in 6,539 conditioning events with an average of 104 events per marked bear. When bear identity was known, conditioning was over 50 times more likely to be applied to adult females than adult males, and in 99% of events where females were accompanied by cubs, cubs were young of year or yearlings. The frequency of conditioning events significantly declined with bear age. Conditioning events most often targeted bears that were feeding on natural vegetation (72%) and conditioning locations were most often at roadsides (65%) and campgrounds (13%).

Among 3,613 events on 39 marked grizzly bears when a response to technician arrival was recorded, the average likelihood of retreat by bears was 32%. As the arrival response, retreat probability increased with the number of actions in the previous conditioning event, the number of conditioning events in the preceding two weeks, and the presence of cubs; retreat likelihood upon technician arrival decreased when noise or projectiles were used in the previous event, when bears were resting or feeding, and with increasing bear age. Among 4,959 events on 46 marked individuals where a response to conditioning was recorded, bears almost always retreated from conditioning technicians (93%) and rarely approached them, either upon technician arrival (1%) or after conditioning commenced (<0.001%). Conditioning events consisted of an average of 2.2 conditioning actions with a total of 14,323 actions, comprised in rank order, by noise (49%), approaches (25%), projectiles (21%) and pursuits (5%). Bears were more likely to retreat from entire conditioning events when the pursuit tool was used, when there were more actions in the event and with increasing distance to cover. Retreat likelihood decreased when noise tools were used, distance to the technician increased, or cubs were present. Within tool types, bears were equally likely to retreat from all three noise deployment methods (human, vehicle, or Karelian bear dogs) and from both approach types (human and vehicle). However, bears were significantly more likely to retreat from contact than no-contact projectiles and from pursuit with humans alone than pursuits with humans and Karelian bear dogs. Responses to both technician arrival and conditioning events were highly variable among individual bears, with bear ID accounting 30-60% of the variance explained by these models.

The distribution of bears and conditioning events in our study suggest that in Kananaskis Country, female bears are disproportionately drawn to feed on natural vegetation, where they can avoid conspecifics via use of a human shield. Conditioning results suggest that bears are more likely to retreat from tools with higher aversive intensity and that they learn over time to avoid areas where conditioning is likely to occur, reducing their use of the human landscape during peak reproductive years for female bears. This, along with the other conflict management tools used in Kananaskis Country (bear-proof garbage, attractant management etc.), may contribute to the high reproductive success of this population. I suggest future AC programs to support human-wildlife coexistence should (a) consider the drivers of conflict (such as human shield dynamics and availability of natural attractants) on the landscape when setting program goals and defining program success metrics (such as an increase in wariness, or a decrease in developed site use), (b) develop conditioning and data collection protocols to adhere to learning theory and specific rules of effective punishment (such as higher intensity treatments and events), and (c) incorporate strategic planning recommendations of assessment and modification of program metrics on a regular basis to enable reporting of future programs.

PREFACE

Aversive conditioning protocols described in this thesis were designed primarily and collaboratively by Carrie Hunt (Wind River Bear Institute) and Jon Jorgenson, John Paczkowski and Jay Honeyman (Government of Alberta; Alberta Environment and Protected Areas and Alberta Forestry Parks and Tourism). Conditioning data were collected by hundreds of individuals in Kananaskis Country, Alberta from 2000 to 2019. Collected data were compiled, stored and curated by the several individuals associated with the Government of Alberta. Derek Ryder compiled and conducted preliminary cleaning of the conditioning dataset. Scott Jevons provided the map of the study area. Sarah Heemskerk assisted with preliminary literature searches for material presented in SM1, SM2, SM3 and SM4. The chapter that follows was formatted for submission to the journal PLoS One with the following authors: Claire Edwards, John Paczkowski, Carrie Hunt, and Colleen Cassady St. Clair.

ACKNOWLEDGEMENTS

This project was made possible through the long dedication and support of many people and organizations. I am deeply grateful to Carrie Hunt, John Paczkowski, Jay Honeyman, Melanie Percy and Jon Jorgenson and for establishing and maintaining the Kananaskis Country aversive conditioning Program for over 20 years, and providing me with the data for this project. I'm particularly grateful to Carrie Hunt and the Wind River Bear Institute for pioneering and implementing the program protocols, and to both Carrie and Lori Homstol for mentoring me through my time in Kananaskis Country. I thank the hundreds of staff; Alberta Conservation Officers, human-bear conflict specialists, biologists, volunteers and seasonal technicians who conducted this management program and collected the data, particularly Tom Partello, Gerry Hurley, Derek Ryder, Randy Axani, Randy Ramsden, Arian Spiteri, Nick Dykshoorn, Russ Talmo and Trent Roussin. This work was financially supported by the Government of Alberta, Alberta Forestry, Parks and Recreation, and two grants to Colleen Cassady St. Clair; a Natural Sciences and Engineering Research Council of Canada Discovery Grant and a Faculty of Science Research Fellowship from the University of Alberta.

This work wouldn't have been possible without the support of my supervisor Colleen Cassady St. Clair. I'm grateful to her for facilitating this opportunity, for her guidance, her skill as a scientist, and her commitment to human-bear conflict management. I'm grateful to my committee; John Paczkowski for his mentorship, encouragement, and enthusiasm, and Andy Derocher, for his kindness and for providing helpful comments and feedback. I'm grateful to my Edmonton friends; Elène Haave-Audet, Gabrielle Lajeunesse, Sage Raymond, Peter Thompson, Cassie Stevenson, Grace Enns, Jenny Foca, Phil Walker and Sean Konkolics for their technical support, and particularly to Carrie Ann Adams, for her assistance with data analysis and R script. I'm also extremely grateful to all of the anonymous humans of Stack Overflow, without whom I would probably still be coding.

I am especially grateful for the support of my family; my parents Jill and Richard for their unwavering support, enthusiasm and care throughout this process. To my siblings Anna and Tom, my partner Ray Schmidt, and to my extended family; Natalie Stafl, Jen Stelfox, Lenka Stafl, Madeleine Martin-Preney, Robyn Hooper, Jill Middlemiss and Cheryl Hojnowski for their years of support, both technical and emotional.

Finally, my deepest thanks go to the animals of this program; the Karelian bear dogs who supported us with all their hearts: Eilu, Blaze, Cassidy, Kuma, Mica, Akela, Sisko, Soledad and most importantly, my partner Grace, for teaching me everything I needed to know. Lastly, I thank the grizzly bears who participated in this work, may it all be worthwhile.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SUPPLEMENTARY MATERIAL

CHAPTER 1

Aversive conditioning of grizzly bears produces high probabilities of retreat from human-bear conflict locations

INTRODUCTION

Human population growth and urbanization cause rising interactions between humans and bears (*Ursidae spp*. Penteriani et al. 2016, Johnson et al. 2018b) with associated increases in human-bear conflict (Can et al. 2014). Although bears are naturally wary around people (Sahlen et al. 2015), their tolerance for humans and human-dominated landscapes may increase if those areas provide rich anthropogenic or natural food (Smith et al. 2005, Penteriani et al. 2018), support travel between patches of suitable habitat (Northrup et al. 2012a), or provide protection from larger, dominant conspecifics (Elfström et al. 2012). On landscapes where the needs of bears and humans overlap, bears can adapt to human use in a variety of ways.

While sharing anthropogenic landscapes, bears can attempt to avoid people via increased nocturnality (Gaynor et al. 2018), by avoiding areas with high human-use (Mueller et al. 2004, Coleman et al. 2013, Hojnowski 2017), or by moving away from human approaches (Ordiz et al. 2013). In human-dominated landscapes where food resources are abundant, drivers of human-bear conflict and co-occurrence are varied. Bears may become more tolerant of both conspecifics and people, especially if their interactions with people are consistently benign (Herrero et al. 2005). Some bears may seek out areas of high human-use if it provides security from conspecifics. This distribution is commonly referred to as the human shield and is evident in ungulates (Berger 2007, Atickem et al. 2014), primates (LaBarge et al. 2022) and bears (Steyaert et al. 2016). Mutual habituation and co-occurrence of people and bears can be sustainable in protected areas (Aumiller and Matt 1994) if it does not cause food conditioning, a process where bears learn to associate people with high caloric food (Herrero and Higgins 2003, Smith et al. 2005) or compromise perceptions of security for people or bears, all of which rapidly escalate as human-bear conflict (Mattson et al. 1996).

Human-bear conflict results when wild bears cause actual or perceived harm to people, or threaten human livelihoods, property or safety (Human-Bear Conflicts Expert Team of the IUCN SSC Bear Specialist Group 2019b). Human-bear conflict is increasing on all four continents inhabited by bears (Can et al. 2014). For people, this conflict frequently reduces economic prosperity, perceptions of security, and societal tolerance for threatened populations of bears (Human-Bear Conflicts Expert Team of the IUCN SSC Bear Specialist Group 2019a). In developed countries, such losses may be less acute than in developing countries, but human-bear conflict remains a substantial problem on landscapes associated with agriculture (Wilson et al. 2006, Northrup et al. 2012b), industry (Bentzen et al. 2014, Proctor et al. 2020), urban centers (Don Carlos et al. 2009, Booth and Ryan 2019) and protected areas (Gunther et al. 2004). These challenges occur in protected areas partly because grizzly bears are among the most sought after species for wildlife tourism in North America and Europe (Penteriani et al. 2017). In protected areas wildlife managers have triple mandates to protect and maintain populations of threatened species (Kubo and Shoji 2014), while supporting high quality visitor experiences (Gunther et al. 2018, Elmeligi et al. 2021), and maintaining visitor safety (Kubo and Shoji 2016).

Historically, management of carnivores, including bears, in protected areas has involved frequent use of reactive tools that included destruction and translocation of conflict-prone individuals (Craven et al. 1998, Treves and Naughton-Treves 2005, Spencer et al. 2007). For bears, these tools are limited by the threatened status of some populations (Cotton 2008, Festa-Bianchet 2010), increasing public opposition to removal of individuals (Agee and Miller 2009), and evidence that hunting and removal of conflict individuals do not always resolve human-bear conflict (Lennox et al. 2018). Consequently, many jurisdictions, particularly in North America, have increased their use of more proactive conflict management techniques. These typically involve securing bear attractants (Otto and Roloff 2015, Johnson et al. 2018a, Morehouse et al. 2021), increasing human tolerance of bears through education and compensation (Gore et al. 2006, Pienaar et al. 2015, Morehouse et al. 2018), and altering the behaviour of individual bears (Can et al. 2014).

The behaviour of individual animals can be manipulated via associative learning with both rewards and punishment (Domjan 1982). Positive reinforcement can occur via diversionary feeding (Garshelis et al. 2017, Morehouse and Boyce 2017), but negative reinforcement is more commonly applied. It may take the form of conditioned taste aversion (reviewed by Snijders et al. 2021), which teaches animals to avoid particular foods or scents (Appleby et al. 2017, Tobajas et al. 2020), or aversive conditioning and hazing (Can et al. 2014). Hazing consists of a negative stimulus that is expected to deter animals from conflict situations in the short term, whereas aversive conditioning (hereafter AC) teaches animals to avoid conditions associated with negative stimuli, like people or locations, over time (Hopkins et al. 2010). The ultimate goal of AC is the reduction of future conflict through behavioural adaptation by the targeted individuals. Hazing and AC have been used to modify conflict behaviour in a variety of wildlife species including corvids (*Corvidae*) and other birds (Cox et al. 2004, Gabriel and Golightly 2014), canids (*Canidae*, Hawley et al. 2013, Appleby et al. 2017, Bonnell and Breck 2017) elk (*Cervus canadensis*, Kloppers et al. 2005, Found et al. 2018), felids (*Felidae*, Alldredge et al. 2019, Petracca et al. 2019), and bears (*Ursus spp*., Rauer et al. 2003, Mazur 2010, Homstol 2011, Lackey et al. 2018). These tools may encourage changes in space use (e.g., Woolridge and Belton 1980, Leigh and Chamberlain 2008), diel activity (e.g., Beckmann et al. 2004, Huffman 2010), or increased wariness to people (e.g., Mazur 2010, Homstol 2011).

In bears, hazing and AC have been used to mitigate conflict in contexts ranging from co-occurrence with humans in protected areas (Gillin et al. 1994, Madison 2008) to protection of livestock in rural landscapes (Anderson et al. 2002, Rauer et al. 2003), (Supplementary Material 1). These tools employ aversive stimuli that range from human signals, such as shouting (Aumiller and Matt 1994), to use of pain-causing stimuli, such as projectiles or electrical shock (Dorrance and Roy 1978). Well-known principles of learning theory, suggest that AC should be most effective when it is applied consistently, immediately, with high initial intensity and without signaling, (Domjan 1996). To be effective, aversive stimuli should have evolutionary relevance (Garcia et al. 1974, Conover 2002) and punishment may generally be more effective if alternative behaviour is rewarded (Domjan 1996). These principles are rarely apparent in the application of AC and hazing to reduce conflict-prone behaviour by bears (Mazur 2010, Homstol 2011). Additionally, there is a wide range of metrics used to report program success (Supplementary Material 2), and no literature synthesis on the efficacy of AC in bears or other wild carnivores. Although there are increasing numbers of publications compiling tools and techniques for responding to, and resolving to human-bear conflicts (Spencer et al. 2007, Beausoleil 2014, Beausoleil and Lackey 2015), (Supplementary Material 3), few papers measure the success of hazing and AC programs for habituated grizzly bears (Gillin et al. 1994, Rauer et al. 2003, Honeyman 2008), (Supplementary Material 2), or describe strategic planning and adaptive management in human-bear conflict mitigation (Can 2021).

The purpose of this study was to describe and evaluate aspects of a long-term AC program on grizzly bears (*Ursus arctos horribilis*) in Kananaskis Country, where bear survival is high (Garshelis et al. 2005) despite high levels of overlapping human-use in several commercial and recreational areas. There, a provincial ministry (currently Alberta Forestry, Parks and Tourism) partnered in 2000 with the Wind River Bear Institute (www.beardogs.org) to develop and implement a program that monitored radio-collared bears, potential attractants, and human activity to anticipate and prevent bear-human conflict. They achieved this with a combination of tools that included attractant management, seasonal closures of some areas, public education, and enforcement of bylaws, that were complemented by AC of grizzly bears. Together, these management tools produced a 50% reduction in grizzly bear mortality and relocations in the core area (Peter Lougheed Provincial Park) between 2000 and 2008 (Honeyman 2008). Here we investigate the AC portion of this program with objectives to (a) describe and summarize the scope of the program, (b) quantify the type and frequency of tools used to condition bears and (c) evaluate correlates of conditioning success. We measure success as retreat by bears from sites of potential conflict as conditioning technicians arrived, following each action, and after events comprised by a series of actions were completed. We additionally evaluated the efficacy of deployment methods within tool types. We interpret our results in the context of learning theory and strategic planning to guide research and management for similar programs in the future.

STUDY AREA

This research was conducted in the Kananaskis Valley in southwestern Alberta, which includes Peter Lougheed Provincial Park (50.72°N, 115.12°W; 600 km^2) and other portions of Kananaskis Country, a 4,500km^2 area comprised of multiple management zones (Figure 1). Around 75% of Kananaskis Country is protected by Wildland Provincial Park and Provincial Park designation, the remainder is leased crown land and private land. Kananaskis Country is bounded by Banff National Park to the west and agricultural and recreational properties to the south, east, and north. It is situated in the Rocky Mountains with elevation ranging from around 1,200m in the valley bottom, to over 3,000m. The Valley bottoms are dominated by coniferous forests of lodgepole pine (*Pinus contorta*) and white spruce (*Picea glauca*) along with important bear foods like buffaloberry (*Shepherdia canadensis*), dandelions (*Taraxacum officinale*), horsetails (*Equisetum sp.*), and sweet vetch (*Hedysarum sp.*). Alpine and subapline zones are dominated by subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), alpine larch (*Larix lyallii*) along with important bear foods like yellow glacier lily (*Erythronium grandiflorum*) and whitebark pine (*Pinus albicaulis*).

Kananaskis Country is a multiple-use landscape dominated by activities like recreation, hiking, grazing, hunting and recreational off-road vehicle use. The only year-round residents are members of Alberta Parks Staff but there is steadily increasing seasonal visitation recently reaching 5.5 million people per year. Kananaskis Country also hosts a stable or increasing breeding population of around 16 grizzly bears/1,000km^2 (Garshelis et al. 2005). Interactions between humans and grizzly bears are common during the active bear season, with multiple public reports of sightings and interactions per day. The core protected areas of Kananaskis Country are outfitted with bear-proof waste management containers (Haul-all; https://haulall.com), making food conditioning extremely rare in this population. However, bears exhibit a high level of multi-generational habituation in front-country habitats.

METHODS

Grizzly bears that regularly spent time in human-use zones were captured in culvert traps or free-range darted similar to methods described by Honeyman (2008) between 2000 and 2019. Captured bears were fitted with a numbered ear-tag and radio collar or ear-tag transmitter; Very High Frequency (VHF) radio collars were used from 2000 - 2014 and predominantly Global Positioning System (GPS) Iridium radio-collars (Vectronic Aerospace GmbH, Berlin, Germany and Followit, Lundesberg, Sweden) were used from 2014 - 2020. Capture and immobilization methods followed Alberta Wildlife Animal Care Committee Class protocol and were approved by the Alberta Ministry of Environment and Sustainable Resource Development and Alberta Ministry of Environment and Parks.

Aversive conditioning

From 2000 to 2019, teams of 1-3 Alberta Parks biologists, conditioning technicians, volunteers, and human-bear conflict specialists from the Wind River Bear Institute (hereafter technicians) patrolled human-use zones in the Kananaskis front country, focusing on the core protected areas of the park; Peter Lougheed and Spray Valley Provincial Parks. Within the study area, regions were designated as red, orange, or green to delineate appropriate areas for aversive conditioning (hereafter AC). Red zones were areas of human-use that were not considered appropriate habitat for grizzly bears to feed, rest in, or travel through (e.g., campgrounds, backyards, and day use areas); orange zones permitted bear use when people were not present (e.g., golf course, trails, and roadsides). Green zones were areas with natural bear habitat that were out of sight of high use areas, where bears were rarely conditioned, except when the proximity of the green zone to an area of high human-use put members of the public at risk of a close-range encounter (e.g., a meadow on the edge of a campground). In red and orange zones, patrols were conducted from dawn until dusk (approximately 0600h to 2300h each day throughout the active bear season (April - December) primarily by monitoring grizzly bear radio-collar frequencies, but technicians also responded to calls from members of the public reporting bear sightings and encounters. Bears within 50m of a human-use zone were prioritized for AC. If more than one bear was in a human-use zone at once, bears were triaged for conditioning by the associated level of human-use, whether they were marked, and whether they had cubs.

AC protocols were established through a partnership with Alberta Parks, Alberta Sustainable Resource Development, and the Wind River Bear Institute (hereafter referred to as WRBI). Protocols were based on the WRBI Bear Shepherding Guidelines, with the goal of teaching bears to non-defensively retreat from humans in encounters and avoid human-use zones when humans were present (Hunt 2008). Conditioning protocols aimed to use operant conditioning and learning principles of immediacy and consistency, by monitoring bears on the periphery of human-use zones in order to condition them as soon as, and every time, they entered the red, or human-use zone (defined above). Technicians attempted to reduce signaling treatment in advance by using a combination of marked and unmarked cars and plain clothes staff. High intensity and evolutionary relevance were achieved by subjecting bears to stimuli that were genuinely aversive (*sensu* Domjan 1996). Conditioning consistently ceased when a bear showed the desirable behaviour of retreating to cover, emulating a reward for alternative behaviour. The program employed stringent safety protocols for people and bears by maintaining escape routes for bears, ensuring large enough teams to prevent bears from challenging technicians, and applying stimuli such that bears could move at walking speed when in high human-use zones (Hunt 2008). Dependent cubs were not targeted for AC in our protocols, but experienced conditioning indirectly through actions directed at their mothers. Occasionally juvenile bears (under the age of four) were conditioned when they were orphaned or independent from the female.

Any combination of conditioning tools could be used in a conditioning event and tools were employed at the discretion of the technician based on exhibited conflict behavior. However, conditioning events typically commenced with noise emanating from one or more of vehicles, dogs, and people. Technicians were instructed to shout, whenever possible, before any other conditioning action occurred to ensure the bear identified humans as the source of subsequent actions (Hunt 2008). Noise was followed by the technician approaching the bear, firing a projectile and/or pursuing the bear. Over the course of the program, bears were conditioned using 20 different tools that varied in tool type and deployment method. We subsequently categorized tool types as noise, approach, projectile, and pursuit (Table 1). Noise deployment methods emanated from vehicles (i.e., sirens and horns), dogs (i.e., barking), and people (i.e., shouting, clapping, racking shotgun). Approach deployment methods included vehicles and humans on foot. Projectiles were divided into those that were designed not to contact the bear (crackers and screamers) and those that were aimed at the bear (rubber bullets, bean bags, paintballs etc.). When contact projectiles were used, the intention was to hit the bear in the hindquarter, rather than hitting adjacent trees and vegetation. Pursuit was divided into pursuit with technicians alone and pursuit by technicians accompanied by Karelian bear dogs (hereafter dogs; Table 1). These dogs were bred and trained by the WRBI to detect, pursue and intimidate bears in partnership with human handlers (www.beardogs.org). Dogs were worked primarily on leash or from a vehicle, due to the high human use nature of the Kananaskis Valley. Bears were conditioned until the conflict situation abated, or the bear showed the desirable behaviour of retreating from the technician.

Following each conditioning event, technicians recorded the conditioning tools used and the behavioural responses by bears in two timeframes; bear response when the technician arrived on scene (hereafter arrival response), and the immediate response to each individual conditioning tool type and deployment method used in the conditioning event (hereafter action response). Up to five actions were recorded for each conditioning event, to which we collectively assigned a binary response variable of retreat or non-retreat (hereafter event response; Table 3). From 17 possible behavioural response categories, we grouped bear responses into five categories (Goumas et al. 2020). We assigned retreat whenever bears moved away from the technician following a conditioning action, which was recorded by technicians in six different ways (retreat, retreat to cover, retreat walk, retreat run, walk to cover, run to cover). Non-retreats included situations where the technician couldn't see the bear, or the bear was unaware of the technician (unaware), the bear was alert or aware of the technician (assess), the bear was indifferent to the technician or stood its ground (ignore), and the bear reduced distance to the technician, bluff charged, approached with curious intent, or approached in a predatory manner (approach; Table 2). In addition to the conditioning tools used and the responses of bears to their actions, staff recorded the identity of marked bears, the known (or estimated) age and sex class of unmarked bears, presence and number of cubs, date, time, and location of the event, the land cover or human-use context of the location, and the activity of the treated bear upon their arrival on scene in categories of feeding, travelling, resting, mating, and other.

Data collection methods changed through time. Between 2000 and 2005, data were collected on paper data sheets; from 2005 to 2014, data were collected on palm pilots; and from 2015 to 2019 data were collected with a cell phone app that georeferenced and autosaved records (ArcGIS Survey123; https://survey123.arcgis.com). Following data entry by field staff, data were compiled and stored in 14 different databases between 2000 and 2019. Alberta Parks staff and volunteers homogenized data in 2020 by condensing several categories to emphasize no more than five unique conditioning tools per single event. They did so by eliminating records describing vehicle approaches and shouting when the number of conditioning actions in an event exceeded five, causing these tools to be underrepresented in our analyses. In addition, the format of the conditioning datasheet changed over the duration of the program, so some interpretation of events was required by staff to transform all of the data into a single database.

Data summary

To provide descriptive information about the program, we qualitatively identified who, where, when, what, and how grizzly bears were conditioned in Kananaskis Country from 2000 to 2019 (Grimes and Schulz 2002). We summarized the sex, age, identity and breeding status of bears being conditioned and computed Spearman's rank correlation to test the relationship between bear age and the per-individual number of conditioning events. We also summarized the type of human-use landscape on which conditioning events occurred, and investigated number of conditioning events by year, month, and natural attractant season. We divided seasons relevant to berries as attractants (pre-berry season: April 1 - July 14; berry season: July 15 - September 7; post-berry season: September 8 - October 31), (Munro et al. 2006, Laskin et al. 2019). We also investigated variables pertaining to the conditioning program; the number of conditioning technician days per season, the number of conditioning events (defined as independent engagements with one individual and their dependent cubs), the number of actions within events (defined as each tool deployed during the conditioning event), the conditioning tool types, the tool deployment method within conditioning tool type, and responses of bears in relation to these tools. For this data summary, we explored the entire database of 6,539 AC events on 48 marked bears and an unknown number of unmarked bears.

Statistical analyses

To examine the efficacy of different conditioning tool types and deployment method within tool types used for AC in Kananaskis Country, we used Chi-square, univariate, and multivariate logistic regression to compare bear responses of retreat from technician to predictor variables related to conditioning tools and demographic and behavioural variables of bears. We investigated bear responses to conditioning in three time periods; response when the technician arrived on scene before the conditioning event began (hereafter arrival response), bear response at the conclusion of an AC event (hereafter event response), and the immediate response to each individual tool, along with deployment method used in the conditioning event (hereafter action response). Analyses of arrival responses were intended to determine how previous conditioning actions affected bear responses to technicians. The event response analysis determined the cumulative effect of all associated actions. The action response investigated the immediate response of bears to conditioning tool types and deployment methods in two analyses. First, we performed a Chi-square test of independence to assess the relationship between categories of bear response across categories of conditioning tools. Following a chi-square test of independence, we computed pairwise comparisons of each bear response and conditioning tool type using Pearson's residuals with a Bonferroni adjustment to reduce likelihood of type one errors. We further tested methods of tool deployment against one another within each conditioning tool type using logistic regression, retaining grizzly bear ID as a random effect. To assess the impact of grizzly bear ID on responses to technician arrival, we included only known individuals who were conditioned more than once in their lifetime and for which an arrival response was recorded (39 individuals, 3,613 events). To assess the impact of grizzly bear ID on responses to conditioning actions and events, we included only known individuals for which responses to conditioning actions and events were recorded (46 individuals, 4,959 events and 5,662 actions within events).

For each of the multivariate logistic regression analyses (arrival and event responses), we created a list of conditioning, demographic and behavioural covariates that we expected to influence bear responses to conditioning across each response timeframe; all continuous covariates were standardized with a mean of zero and a standard deviation of one. To identify variables for subsequent use in sets of multivariate models, we first applied univariate tests via logistic regression on the binary retreat response variable for each analysis (Table 3) and included grizzly bear ID as a random effect. In the arrival response analysis, we tested a binary response variable of grizzly bear retreat before the conditioning event began against six covariates associated with conditioning and 14 covariates associated with demographic, landscape and behavioural factors. We assessed the number of past conditioning events across ten different time periods (the previous event, previous day, and previous one/two/three/four/five/six/seven/eight weeks) to find the most explanatory time period. In the event response analysis, we tested a binary response variable for retreat at the end of a conditioning event against six covariates associated with conditioning and 14 covariates associated with demographic, landscape and behavioural factors. We analyzed action responses among deployment methods separately for each of the four tool types, again using a binary response variable of immediate retreat.

We retained for multivariate models the variables meeting a liberal significance value of $P < 0.25$ in univariate tests (Table 3; Hosmer and Lemeshow 2000). We compared all subsets of the retained covariates to the binary response variable of retreat in a global logistic regression model using a binomial family distribution and logit link function using R package "lme4" (Bates et al. 2015) with grizzly bear ID as a random effect. For each analysis we used the dredge function to identify top models using R package "MuMin" (Bartoń 2018). We retained in each of the final model sets, all models within 2.0Δ AIC of the top model. For all model sets, we used variance inflation factors in R package "car" (Fox and Weisberg 2011) to investigate correlated variables, and we determined the fit of each model using the R package "performance" (Lüdecke et al. 2021) to calculate marginal and conditional r-squared values (Nakagawa et al. 2017).

RESULTS

Summary of program attributes

Between 2000 and 2019, 48 marked and an unknown number of unmarked grizzly bears were treated as part of the aversive conditioning (hereafter AC) program across 6,539 conditioning events, (Figure 1). When bears were marked (4,969 events, 76%), the mean number of conditioning events per individual was 104 (+/- 207 *SD*, range: 1-963). On average, females were conditioned over a span of 4.6 years, and males for 1.6 years. Age of conditioned individuals ranged from 1 to 29 years. Adults (age ≥8) were conditioned in 3,171 events (48%), followed by subadults (ages 4-7) in 2,264 (35%) events, and juveniles (ages 1-4) in 564 (9%) events. In the remaining 540 events (8%), age was not recorded. There was a significant negative correlation between bear age and the number of conditioning events (Spearman's rank correlation, rho = -0.21, p-value = 0.01; Figure 2).

Female bears were conditioned in 4,216 (64%) events and males in 743 (11%) events, with sex unknown in the remainder of events (1,580, 24%). When sex was known (4,959 events, 75%) and age and sex of bears were combined, adult females were conditioned in 2,788 events (56%), and adult males were conditioned in 65 events (1%). When females were conditioned, they were accompanied by cubs during 1,176 conditioning events (28%). When cub age was recorded (823 of 1,176 events), cubs were young of year in 487 events (59%), followed by yearlings in 331 events (40%). Less than one percent of conditioning events were conducted on females with cubs aged 2-4 years.

When bear activity was recorded before conditioning commenced (5,573 events, 85%), bears were feeding in 4,014 events (72%), travelling in 1,487 events (27%), resting in 62 events (<1%) and mating in 10 events (<1%). When bears were recorded feeding, it was almost always on natural vegetation (3,996 events, 99%), but occasionally on anthropogenic vegetation (e.g. golf courses; 61 events, <1%). Bears were rarely feeding on insects (39 events, <1%), and wildlife carcasses (32 events, <1%). Bears feeding on human attractants (human food, garbage, railway grain and livestock carcasses) accounted for less than 3 conditioning events each (<0.01% each). The type of food attractant was unknown or listed as "other" in 90 events (<1%).

Between 2000 and 2019, 985 conditioning events (15%) took place within a red zone, 2,963 events (45%) took place in an orange zone, and 14 events (0.2%) took place in a green zone. The remainder of events (2,577, 39%) were not categorized by zone. When conditioning events were categorized by land cover and human-use type (4,031, 71%), they took place across 22 different categories, (Supplemental Material 5). In rank order, most events occurred on roadsides (2,608, 65%), followed by front-country campgrounds (518, 13%) and day use areas (274, 7%), trails (150, 4%) facility zones (101, 3%), residential areas (109, 3%) and golf courses (113, 3%). When conditioning occurred, bears were an average of 16m from cover (5,377 events, +/- 22m *SD*, range: 0-500m) and 43m from the technician (5,130 events, +/- 26m *SD,* range: 1-105m).

The total number of conditioning events per year varied with, the number of bears in the conditioning program, and yearly funding available for technicians, in addition to bear behaviour. The average number of staff days per year was 134 (+/- 56 *SD*, range: 13-209; Figure 3); there was a significant positive correlation between number of technician days per year and number of conditioning events per year (Spearman's rank correlation, rho = 0.630, p-value = 0.003). Conditioning events took place an average of 344 times per year (+/- 225 *SD*, range: 56-881). The average number of conditioning events per month within year was 38 (+/- 66 *SD*, range: 0, 350 in August 2011; Figure 3). Number of conditioning events varied by natural attractant season with most occurring during berry season (3,527, 53%), almost as many in the pre-berry season (2,671, 41%) and few in the post-berry season (341, 5%; Figure 3).

Within 6,539 conditioning events, 14,323 conditioning tools or actions were administered with an average number of recorded conditioning actions per event of 2.2 (+/- 0.9 *SD*, range: 1-5). Across all actions within events, a noise tool was used 6,994 times (49%), approaches 3,558 times (25%), projectiles 3,077 times (21%), and pursuit 677 times (5%; Figure 4). When noise was used, a human noise (shouting, clapping) was used 4,469 (64%) times, a barking dog 2,002 (29%) times, and a vehicle noise (horn, siren) was used 523 (7%) times. When approaches were used, they almost always occurred in vehicles (96%), but a few occurred on foot (4%). No-contact projectiles were used in 1,511 actions (49%) and contact projectiles were used in 1,566 actions (51%). Projectiles were recorded as having made contact in 934 (60%) of intended contact actions. In our analyses below, we considered projectiles in the contact category only if they made contact with the bear. Finally, when pursuit was used, it employed only humans in 505 actions (75%) and humans with dogs in 172 actions (25%; Figure 4). The first action to occur in a conditioning event was usually noise (3,113, 48%), then approach (3,032 events, 46%), projectiles (226 events, 3%) and pursuit (165, 3%).

Response to conditioning treatments

Retreat on technician arrival

An arrival response was recorded from 39 marked grizzly bears in 3,613 of 4,959 events (72%) before the conditioning event began. The six categories of arrival response were retreat (1,141, 32%), unaware (2, < 0.01%), assess (1,649, 46%), ignore (813, 23%) and approach (8, < 0.01%). Five of the eight approaches occurred in August and four by a single adult, female bear. In the multivariate logistic regression assessing arrival response, five models were retained that were within 2 AIC of the top model with four conditioning covariates and three demographic and behavioural covariates (Table 4, Figure 5). In the top model, bears were 63% as likely to retreat if the noise tool was used, and 77% as likely if the projectile tool was used in the previous event. Bears were 60% as likely to retreat with each *SD* (4.6 years) of increasing age, and about 25% as likely to retreat if they were feeding or resting, relative to traveling. By contrast, retreat likelihood increased by 9% for each additional *SD* of actions (0.9 actions) bears experienced in the previous event, 27% for each *SD* of additional events (range: 0 - 68, *SD* 13.4) in the previous two weeks, and by 80% if cubs were present. The confidence intervals for when approach tools were used in the previous event, and the time since the previous event overlapped zero, limiting predictive value (Table 5; Figure 5). These models explained 43 and 44% of the variance in the data (Table 4). There was considerable variation among individuals, with the random effect of grizzly bear ID explaining two thirds of that (28 and 29% of the total variance; Table 4).

Retreat from conditioning event

Across 4,959 conditioning events, which contained up to five conditioning actions, the most common response at the conclusion of the conditioning event was one of the six categories of retreat (4,600 or 93%). The multivariate logistic regression produced four top models (Table 6; Figure 6). The top model showed that bears were 42% as likely to retreat when a noise tool was used and 79% as likely to retreat at the conclusion of the event when an approach tool was used (Table 7; Figure 6). By contrast, bears were 3.9 times more likely to retreat when the event contained the pursuit tool (Table 7; Figure 6). The odds of retreat declined by 60% if cubs were present. The odds of retreat increased by 66% with each additional *SD* of actions in the event and by 56% with each *SD* (23m) of distance to vegetative cover; the odds decreased by 19% with each *SD* (26m) increase in distance to the technician. Subadults and juveniles were about 54% more likely to retreat than adults. Bears were 60% less likely to retreat when the behaviour at the time of conditioning was unknown or unrecorded, than when they were travelling. Bears were 2.3 times more likely to retreat when they were resting, as opposed to travelling but the confidence intervals overlapped zero, limiting the predictive power (Table 7; Figure 6). The top models explained 31-32% of the variance in the data with the random effect of grizzly bear ID explaining one third of that (9-11% of the total variance; Table 6).

Retreat from conditioning action

An immediate response to a specific conditioning action within a conditioning event was recorded from known grizzly bears in 5,662 of 14,323 actions (40%) on 46 bears (Table 3), with up to five conditioning actions per event. When response to an action was recorded, the most common response was one of the six categories of retreat (4,870, 86%); most commonly run to cover (2,335, 48%) or retreat run (1,013, 21%). For the remaining actions, bears either assessed (456, 8%) or ignored the technician (321, 6%). Very rarely, bears approached the technician (in 15 actions; 0.003%).

Response to conditioning actions were not evenly distributed across conditioning tool types ($X^2 = 73.122$, df = 9, p-value = <0.001). Testing each bear response category against conditioning tool types in pairwise comparisons revealed that bears were significantly less likely to retreat when noise was used and significantly more likely to retreat when projectile and pursuit were used. Responses of ignore or assess were significantly more likely when approach or noise tools were used (Figure 7).

We conducted a separate logistic regression analysis for each of the conditioning tool types where an immediate response to tool deployment method was recorded. In rank order, the frequency of use by tool type was: noise (dog/human/vehicle, 2314 actions), approach (vehicle/human, 1415 actions), projectile (no-contact/contact, 1715 actions) and pursuit (human/human and dog, 264 actions) (Table 8). There were no significant differences in retreat probability among deployment methods for noise tools (dog, human, vehicle) or approach tools (human or vehicle) (Table 8, Figure 8). Bears were 50% more likely to retreat from projectile tools when they made contact than when they did not make contact, and four times more likely to retreat from humans alone compared to humans with dogs (Table 8, Figure 8). Retreats from individual deployment methods within actions ranged from 82 – 98%, but sample sizes were highly variable among both tools and deployment methods (Table 8, Figure 9)

DISCUSSION

Hazing and aversive conditioning (hereafter AC) programs are frequently used for human-bear conflict management, but little is known about how habituated grizzly bears respond to conditioning and the circumstances that increase bear wariness. In this study, we summarized a long-term grizzly bear AC program based in Kananaskis Country, Alberta, Canada, and modeled the predictive power of covariates describing conditioning events and actions, along with behavioural and demographic covariates, to explain immediate and longer-term grizzly bear retreat from technicians. Among 4,959 events, bears nearly always (93%) retreated from conditioning, demonstrating the efficacy of AC in mitigating potential conflict with people. Bears were more likely to retreat upon the arrival of the technician when conditioning events in the previous two weeks were of higher intensity and frequency. Similarly, bears were more likely to retreat from a conditioning event when it employed tools with greater aversive intensity, particularly pursuit, and when the number of tools used in the event increased. Bears were four times more likely to retreat from projectile tools when they made contact, presumably a more aversive stimulus than projectiles that made noise or smoke trails. Together, our results show that AC generates a high rate of retreat by grizzly bears, but these rates increase when stimuli are more intensive and frequent. However, there was considerable variation among individuals in their responses to AC with bear ID responsible for two thirds of the explained variation for arrival responses and one third of the explained variation for event responses.

Over the 20 years of conditioning events we analyzed, 48 known individual bears, mostly females, were treated over an average of 4.6 years for females and 1.6 years for males with an average of 104 events per individual. This duration and frequency of treatment suggests that AC must be sustained over considerable time periods before bears learn, or choose, to avoid areas designated for human use (e.g., roadsides and campgrounds). Both the number of individuals and the frequency of treatment were much higher in this population than in other published studies of AC in grizzly bears (Gillin et al. 1994, Rauer et al. 2003). AC is frequently used in landscapes where food conditioning and feeding on anthropogenic food sources is prevalent (Dorrance and Roy 1978, Greene 1982, McCarthy and Seavoy 1994, Beckmann et al. 2004), but in Kananaskis Country, consumption of human sources of food was extremely rare, occurring in 0.01% of events. Nonetheless, our study area contained much high-quality natural habitat in areas with high human use and most conditioning events occurred during berry season (53%), targeting bears while they were feeding (72% of events), suggesting that access to food can increase proximity of bears to people, even in this protected area with high security of anthropogenic attractants.

We found that the per-individual number of conditioning events significantly decreased with bear age, declining steeply after the bears reached the age of 11. Adult females were targeted in the majority of conditioning events (51%). When females were accompanied by cubs (28% of events), the cubs were virtually always (99% of events) young of year or yearlings, despite the average age of cub independence in this population being 3.4 years (Garshelis et al. 2005). Together with the low number of conditioning events targeting adult male bears (1%), these results suggest that females were using locations with close proximity to humans as a shield from large male grizzly bears (Elfström et al. 2012), which sometimes exhibit sexually-selected infanticide (Bellemain et al. 2006, Steyaert et al. 2016). Similar use of humans as a shield from predation is described for ungulates (Berger 2007, Atickem et al. 2014) and primates (LaBarge et al. 2022).

There was high variability in the number of conditioning events among years, suggesting that bear use of this landscape depends partly on the abundance and distribution of natural foods, which vary markedly among years, with spring temperatures and precipitation (McClelland et al. 2020). Human use also varies among years, with an increasing trend in our study area over time (H. Edwards et al. 2022). Additional variation occurred in the availability of conditioning technicians, both within and among years. Part of the broader strategy for reducing human-bear conflict in this landscape has been to remove bear-attracting plants, particularly *Sherpherdia canadensis*, from areas designated for human use, such as Lower Lake Campground and William Watson Lodge (Honeyman 2007). Some authors suggest that conditioning may be more effective in years when natural food is abundant (Elfström et al. 2012), presumably because a given foraging patch becomes less valuable to individuals. Unfortunately, we lacked the information needed to qualitatively compare attractant density or quality among years as potential explanatory variables for bear responses.

We examined bear retreat in relation to three sets of predictive variables coinciding with the arrival of technicians, the overall conditioning event, and the deployment methods associated with each of the four conditioning tool types. In addition to describing the use of these techniques in Kananaskis, we sought to determine whether the efficacy of AC could be increased by applying principles of learning theory specific to punishment, particularly high consistency of application and high intensity (Domjan 1982; 1996). The WRBI Bear Shepherding Guidelines suggest use of similar principles to increase conditioning efficacy (Hunt 2008), and here we found some evidence for the importance of these principles.

Bears were more likely to retreat from the arrival of technicians when they had been exposed to more conditioning events in the previous two weeks and when there were more conditioning actions in the most recent event, suggesting that bears learned from past events if they were more consistent. In elk, an intermediate frequency of AC (at a rate of 2-3 conditioning events per month) caused a greater increase in wariness than lower frequencies (Found et al. 2018), and in coyotes, the number of conditioning events in the previous 8 week period lead to a 29-37% increase in probability of subsequent retreat (Lajeunesse 2023). Additionally, habituated macaques that were hazed with noise and contact projectiles at a high rate over a period of two years exhibited reduced habituation and reduced severity of conflict during human encounters (Honda et al. 2019). Bears in our study were less likely to retreat upon technician arrival if noise or projectiles were used in the previous event and if they were resting or feeding, suggesting some habituation to these tools and reticence to retreat from locations with high natural food density or enough security to initiate resting. Bears were more likely to retreat if cubs were present, perhaps to increase cub security before conditioning occurred. Despite the fact that conditioning events became less common as bears aged, bears were also less likely as they aged to retreat from the arrival of technicians, suggesting that individual bears may become desensitized to conditioning with fewer, or less regular applications (Blumstein 2016).

Better evidence that bears responded to AC of higher intensity came from the analysis of retreat from entire conditioning events. Among nearly 5,000 events, bears were more likely to retreat if the pursuit tool was used, which presumably exerts a high threat to bear security. Pursuit was also effective at increasing wariness in habituated elk (Kloppers et al. 2005, Found et al. 2018). Contrary to our result, two studies of black bears found that projectiles were more effective at generating wariness than human approaches or pursuit (Mazur 2010, Homstol 2011). Unlike in our analyses, these studies tested the impact of contact projectiles separately from no-contact (noise and visual) projectiles. When we tested contact and no-contact projectiles against one another in the action analysis, contact projectiles were significantly more effective at producing retreat. Binning both types of projectile in our arrival and event analyses may have underestimated responses to contact projectiles alone. We also found a greater likelihood of retreat when more actions were used within an event, indicative of a more intense and longer period of conditioning. Bears were more likely to retreat when they were farther from cover and closer to technicians, similar to findings for ungulates (Stankowich 2008, Sahlen et al. 2015). Bears were less likely to retreat when cubs were present, perhaps because conditioning did not target cubs, increasing their habituation to technicians, and because females would be unlikely to leave their cubs (Herrero 1976). In this analysis, there was some evidence that bears habituated to the noise tool, which is known to produce habituation in diverse other species that are subjected to repetitive sound-based deterrents, (Bomford and O'Brien 1990, Conover 2002, Ronconi and St. Clair 2005, Blumstein 2016). Adult bears were less likely to retreat from conditioning events than subadults or juvenile bears (under the age of 4), suggesting that younger bears may be more easily intimidated by AC. In some species, there is evidence that boldness and habituation increases as animals age (Petelle et al. 2013, Starling et al. 2013), however other evidence suggests that boldness in larger mammals can be consistent between years and unrelated to age (Found and St. Clair 2016, Myers and Young 2018).

Some final evidence for the greater efficacy of more intensive forms of AC came from the action analysis. Despite retreat being the most common response to conditioning across all conditioning tool types, the lower intensity conditioning tool types of noise and approach were positively correlated with habituation responses of assess and ignore by bears. The higher intensity conditioning tools of projectile and pursuit were negatively correlated with those same responses. Within the projectile and pursuit tools, retreat likelihood increased with the more intensive deployment method of contact projectiles and human pursuits, presumably because these deployment methods induced greater threats to bear security. The contact projectile result is supported by the studies of black bears that found higher responsiveness of bears to pain stimuli (Mazur 2010, Homstol 2011). Pursuit was effective at causing retreat, regardless of the modality, consistent with its use in elk (Kloppers et al. 2005, Found et al. 2018, Found and St. Clair 2018), but pursuit involving humans alone was more effective than pursuits by humans with dogs. This result may stem from a tendency for humans without dogs to conduct AC in larger groups than humans with dogs. In fact, one of the functions of Karelian bear dogs in this program was to increase safety of technicians when working alone or in small groups, particularly when conditioning females with cubs. Other researchers have found that deterrence with dogs does not differ much from deterrence without them (Beckmann et al. 2004, Reich 2022).

In addition to the effects of conditioning, demographic, and behavioural variables on the likelihood of retreat by bears in our study, there was considerable variation among individuals. The random effect of grizzly bear ID accounted for up to two thirds of the variation explained by the top models for both the arrival of technicians (two thirds of the explained variation) and entire conditioning events (one third of the explained variation). Several studies describe the importance of personality, also known as behavioural syndromes, when managing wildlife (Powell and Gartner 2011, Honda et al. 2018, Bombieri et al. 2021), finding that behavioural syndromes can impact efficacy of wildlife management (Honda et al. 2018). For example, bold elk showed greater increases in wariness during AC, but faster extinction of wariness once conditioning ceased (Found and St. Clair 2018). In addition to variation among individuals, conflict progression and development of boldness in animals may follow a predictable pattern (Schmidt and Timm 2007) that has been described in coyotes (Timm et al. 2004), marmots (Petelle et al. 2013), black bears (Myers and Young 2018) and grizzly bears (Bombieri et al. 2021). Several authors have suggested that AC is likely to be more effective when applied to individuals exhibiting novel conflict behaviours (McCullough 1982, Stenhouse 1982, Clark et al. 2002b, Mazur 2010, Skrbinšek and Krofel 2014), but this has only been tested quantitively in bears in one paper (Mazur 2010) where the progression of conflict from habituation to food conditioning was tested. The conflict behaviour in our study was habituation and most conflict locations (e.g., campgrounds and roadsides) attracted bears for natural sources of food. Nonetheless, some consideration of the steps of conflict progression and novelty of conflict behaviour may be important in bears, for which multigenerational habituation is evident and social learning is common (Nielsen et al. 2013, Morehouse et al. 2016).

A large portion (55-70%) of the variation in the data was not explained by our models. It is possible that some of this variation was associated with individual learning, experience or context related to either human-use or conspecifics, which may not be encompassed by the random effect of bear ID. In Kananaskis Country, bears make fine scale adjustments in attempt to avoid the highest human-use areas and times (Hojnowski 2017), and in the Canadian Arctic, bears demonstrate the use of time-dependant spatial-memory to inform different foraging strategies (Thompson et al. 2022). On other landscapes, bears alter their spatial and temporal use of the landscape in order to avoid hunting (Ordiz et al. 2012), human approaches (Ordiz et al. 2013), and conspecifics (Steyaert et al. 2016). Our analyses did not evaluate how bears learned over time, individual differences in memory and learning, bear experience, or the context of conspecifics or humans, all of which are fluid metrics on this complex and dynamic landscape that might confound some of our results.

Despite considerable variation among individuals, and considerable unexplained variance, AC appears to be a safe technique for proactive mitigation of potential conflict with habituated grizzly bears. Bears almost always retreated from conditioning events (93%) and were extremely unlikely to approach technicians either upon their arrival (1%), or after conditioning commenced (<0.001%). The rare instances when bears approached technicians usually involved solo adult female bears in August, which coincides with hyperphagia (Fuchs et al. 2019). The high prevalence of retreats in our study does not support the speculation that AC causes increased aggression by bears (Mattson 2021, Stringham 2017). A similarly high prevalence of retreat from AC was reported by others (Gillin et al. 1994, Rauer et al. 2003). Despite perceptions of risk that come with human-carnivore co-occurrence (Gore et al. 2007, Sakurai et al. 2013), in Kananaskis Country habituated grizzly bears maintained presence on the human-use landscape over many years, without exhibiting the high-level conflict behaviours (depredation, defensive encounters, predatory behaviour) that increase risk for visitor safety. This supports the assertion that AC is an important tool for halting conflict progression (Mazur 2010) and mitigating close range interactions between humans and bears. Nonetheless, the potential for human injury from grizzly bears and persistence in the boldness of some individuals (Bombieri et al. 2019) requires a careful approach, development of stringent safety protocols, vigilance by conditioning technicians, and use of a broad range of management tools.

There were some important elements in this study that limit the generality of its conclusions. First, our post-hoc analyses followed compilation and cleaning of 20 years of management data that were collected by three different agencies employing over 130 technicians and a variety of data collection tools and databases. Our study lacked an explicit experimental design and the learning principles of consistency and intensity that we targeted were chosen after data were collected. Bears were conditioned opportunistically when they exhibited conflict behaviour and were triaged for conditioning based on staff availability, bear reproductive status, past conflict history, and level of human-use in the conflict location. Consequently, bears were often not conditioned immediately once they exhibited conflict behaviour, and conditioning may have commenced some minutes or hours after conflict behaviour began. Once conditioning began, any combination of tools could be deployed based on the technician's discretion, which made it challenging to test the effects of individual tools. Moreover, in the data cleaning and compilation stage, some tools were removed from the database in order to limit each conditioning event to a maximum of five conditioning actions. This meant that some tools, particularly vehicle approach and shouting were underrepresented in our analyses. Finally, although the high frequency of retreats from AC supported public safety, it weakened the statistical power of our response variables.

CONCLUSIONS AND RECOMMENDATIONS

Despite some limitations, our results suggest that the aversive conditioning (hereafter AC) program used between 2000 and 2019 contributed to the high survival of grizzly that characterises Kananaskis Country (Garshelis et al. 2005, Honeyman 2008). In that area, younger females with cubs and subadult bears appear to exploit a human shield, feeding predominantly on natural foods that occur close to human use areas, particularly on roadsides and in campgrounds during pre-berry and berry seasons. Adult female bears were more likely to require increased management input through monitoring and conditioning over longer time spans than adult males, but early management investment may lead to decreased conditioning requirements as bears age.

We found that conditioning is likely to increase wariness responses in grizzly bears and extremely unlikely to cause increased aggressive or defensive behaviour towards humans. Bears were more likely to retreat when they were further from cover and closer to the technician, when they were travelling as opposed to feeding or resting. Although extremely rare, bears were more likely to approach technicians during hyperphagia. Retreat likelihood was high across all conditioning treatments, with bears showing slightly greater responsiveness to conditioning of higher intensity in all three of our analyses, coinciding with the arrival of technicians, upon completion of the conditioning event and in responses to individual actions.

Higher intensity tools are logically able to increase wariness responses when their use adheres to the principles of learning theory, however our results suggest that it might not be reasonable to expect a conditioning program like this one to exclude bears from the human-use landscape in the short term, especially when the landscape is high in time-limited resources such as berries during late summer, or if the human shield offers protection from conspecifics such as large male grizzly bears. If the use of higher intensity tools on habituated bears are only marginally more effective than lower intensity tools, it may be important to consider how, where, and when they should be used to maximise their efficacy while maintaining an ethical management program. It is important that managers be clear about specific goals for changing bear behaviour, setting reasonable metrics for success based on these parameters, rather than parameters that may not be attainable through such management programs. Despite being unlikely to exclude bears from the human-use landscape, programs such as this one may increase bear wariness, or improve the behavioural responses of bears to humans when they encounter them. Additionally, the decline in conditioning events with bear age suggests that over time bears learn to avoid the locations where conditioning is likely to occur, and decrease their need to exploit the human shield during their peak reproductive years, potentially increasing their reproductive success and contributing to the recovery of this provincially threatened population.

Resolving human-bear conflict requires integrating the use of multiple tools (Spencer et al. 2007, Can et al. 2014) along with strategic planning (Marchini et al. 2019) and active adaptive management (Ohta et al. 2012, Schaefer et al. 2021). Future AC programs could be improved in several ways and we offer specific recommendations. First, managers should define the particular program goals and metrics with which to define success, such as changes in the probability that bears retreat from approaching people, or a decrease in use of developed sites, and ensure that these metrics and use of conditioning tools are appropriate for the drivers of conflict on the landscape. Second, managers should attempt to employ the principles of learning theory that apply to punishment; immediacy, consistency, high initial intensity, and lack of advance signalling (Domjan 1982; 1996). Additionally, aversive stimuli should be evolutionarily relevant (Garcia et al. 1974) such as by pairing the approach by people with chases or pain. Whenever possible, alternative desired behaviours, such as retreating to cover, should be rewarded by the cessation of conditioning (Hunt 2008). Procedures should reflect these principles, be consistently taught to staff, implemented, and evaluated to enable assessment of how and which specific protocols and tools result in desired behaviour by conflict individuals. Careful data collection will increase the rigour of future studies, supporting the continuous refinement of techniques to maximize learning efficacy and public safety, while maintaining ethical management programs.

TABLES AND FIGURES

Table 1. Conditioning tools deployed by technicians and post-hoc categorization into tool deployment method and conditioning tool type categories.

Conditioning tools deployed by technicians in the Kananaskis Country aversive conditioning program from 2000 to 2019 (left column), post-hoc categorization of tools into tool deployment method (middle column), and conditioning tool type categories used for analysis in the arrival, event and action response analyses (right column). Dogs used for noise and pursuit conditioning were Karelian bear dogs.

<table>
<tr><th>Conditioning tool deployed during event</th><th>Post-hoc tool deployment method categorization</th><th>Post-hoc conditioning tool type categorization</th></tr>
<tr><td>Horn</td><td rowspan="2">Noise vehicle</td><td rowspan="7">Noise</td></tr>
<tr><td>Siren</td></tr>
<tr><td>Barking dog</td><td>Noise Dog</td></tr>
<tr><td>Voice</td><td rowspan="4">Noise Human</td></tr>
<tr><td>Shout</td></tr>
<tr><td>Clapping</td></tr>
<tr><td>Shotgun rack</td></tr>
<tr><td>Vehicle approach</td><td>Approach vehicle</td><td rowspan="2">Approach</td></tr>
<tr><td>Foot approach</td><td>Approach human</td></tr>
<tr><td>Cracker 9mm</td><td rowspan="3">Projectile no-contact</td><td rowspan="8">Projectile</td></tr>
<tr><td>Screamer 9mm</td></tr>
<tr><td>Cracker 12 gauge</td></tr>
<tr><td>Rubber bullet</td><td rowspan="5">Projectile contact</td></tr>
<tr><td>Paintball</td></tr>
<tr><td>Bean bag</td></tr>
<tr><td>Pepper spray</td></tr>
<tr><td>Thumper gun</td></tr>
<tr><td>Pursuit</td><td rowspan="2">Pursuit human</td><td rowspan="3">Pursuit</td></tr>
<tr><td>Pursuit no dog</td></tr>
<tr><td>Pursuit with dog</td><td>Pursuit human and dog</td></tr>
</table>

Table 2. Behavioural responses recorded by technicians, post-hoc categorization into response groups and binary retreat categorization.

Behavioural responses of grizzly bears recorded by conditioning technicians in the Kananaskis Country aversive conditioning program from 2000 to 2019 (left column), post-hoc categorization of responses following Goumas et al. (2020) (middle column) and binary retreat categorization used for analysis in arrival, event and action responses (right column).

Behavioural response recorded during event	Behavioural response category (Goumas et al. 2020)	Binary retreat response
Retreat	Retreat	Retreat (1)
Retreat to cover		
Retreat walk		
Walk to cover		
Retreat run		
Run to cover		
Unaware	Unknown	No retreat (0)
Unknown		
Aware	Assess	
Indifferent	Ignore	
Stands ground		
Close distance	Approach	No retreat (0)
Curious approach		
Bluff charge		
Charge		
Predatory approach		

Table 3. Logistic regression model structure examining binary response (retreat vs. no retreat) of grizzly bears to aversive conditioning in the arrival, event and action responses.

Testing responses to previous conditioning (arrival response) and conditioning in the current event (event and action responses). Each biological and conditioning response variable was initially assessed with univariate tests of covariates for which those with a P < 0.25 are presented in bold font and were retained for testing in multivariate models (after Hosmer and Lemeshow 2000).

Analysis	Sample size	Binary response variable	Conditioning timeframe	Conditioning treatments	Conditioning covariates	Biological covariates
Arrival response	3613 events, 39 individuals	Retreat on arrival of conditioning technician, before conditioning commenced	Response to previous conditioning actions and events	Whether each conditioning tool type was used in the previous event - **Noise, Approach, Projectile,** Pursuit	**Time (hrs) since last conditioning event, Number of actions in the previous event, Number of events for each individual in the day/week/2 weeks/3 weeks/4 weeks/5 weeks/6 weeks/7 weeks/8 weeks/**year preceding the current event	**Bear age,** sex, **presence of cubs,** cub age, **time since entry to the conditioning program, activity when the technician arrived on scene,** attractants the bear was feeding on, landscape type where conditioning action took place, **distance of the bear from cover, distance of the bear from the technician,** diel category, **month, natural attractant season** and **year of conditioning**
Event response	4959 events, 46 individuals	Retreat at end of the conditioning event (up to five conditioning actions)	Response at the end of the conditioning event	Whether each conditioning tool type was used in the current event - **Noise, Approach, Projectile, Pursuit**	**Number of conditioning actions in the event,** time since entry into the conditioning program	**Bear age**, **sex, presence of cubs**, cub age, number of cubs, **activity when the technician arrived on scene,** attractants the bear was feeding on, landscape type where conditioning action took place, **distance of the bear from cover, distance of the bear from the technician, diel category, month, natural attractant season** and year of conditioning
Action response	5662 actions, 46 individuals	Retreat after delivery of each conditioning action or tool	Response after delivery of conditioning tool	Deployment method within tool type: **Noise (vehicle/human/dog). Approach (vehicle/human), Projectile (no-contact/contact) Pursuit (human/human & dog)**	None	None

Table 4. Final model set of logistic regression of retreat by grizzly bears on arrival of the conditioning technician.

Final model set (≤ 2 AIC_c from the top model) predicting grizzly bear retreat on arrival of conditioning technician (arrival response) in Kananaskis Country from 2000 to 2019 with degrees of freedom (df), log likelihood, AIC_c score, delta AIC, model weight, conditional and marginal R^2 values from multivariate logistic regression models. Bear ID was included as a random effect.

Model	df	Log likelihood	AICc	Delta AIC	AICc weight	Conditional R^2	Marginal R^2
Model 1	11	-1771.25	3562.79	0.000	0.137	0.435	0.149
	Arrival.retreat ~ (Grizzly bear ID) + Activity + Age + Cubs present + Number events in previous 2 weeks + Number of actions in last event + Noise tool used in last event + Projectile used in last event						
Model 2	10	-1770.36	3562.55	0.234	0.122	0.429	0.148
	Arrival.retreat ~ (Grizzly bear ID) + Activity + Age + Cubs present + Number events in previous 2 weeks + Noise tool used in last event + Projectile used in last event						
Model 3	11	-1770.98	3564.03	1.479	0.065	0.432	0.148
	Arrival.retreat ~ (Grizzly bear ID) + Activity + Age + Cubs present + Number events in previous 2 weeks + Time (in hours) since the previous event Noise tool used in last event + Projectile used in last event						
Model 4	12	-1770.09	3564.27	1.719	0.058	0.433	0.149
	Arrival.retreat ~ (Grizzly bear ID) + Activity + Age + Cubs present + Number events in previous 2 weeks + Number of actions in last event + Noise tool used in last event + Projectile used in last event + Pursuit tool used in last event						
Model 5	12	-1770.09	3564.27	1.721	0.058	0.437	0.149
	Arrival.retreat ~ (Grizzly bear ID) + Activity + Age + Cubs present + Number events in previous 2 weeks + Number of actions in last event + Time (in hours) since the previous event + Noise tool used in last event + Projectile used in last event						
Model 6	11	-1771.12	3564.31	1.756	0.057	0.433	0.148
	Arrival.retreat ~ (Grizzly bear ID) + Activity + Age + Cubs present + Number events in previous 2 weeks + Noise tool used in last event + Projectile used in last event + Approach used in last event						

Table 5. Variable attributes predicting probability of grizzly bear retreat in the arrival analysis logistic regression. Variable attributes from the top model (Table 4) predicting probability of retreat for grizzly bears in Kananaskis Country on arrival of the conditioning technician (arrival response) from 2000 to 2019. Columns show variable attributes including both measured percentage and modelled probability of retreat for each variable. Absolute probability of retreat was calculated summing the coefficients for the intercept and each parameter, exponentiating the sum to produce a combined odds ratio and then dividing that value by one plus the odds ratio (OR/(1+OR)).

Variable levels		Coefficient	Standard Error	p-value	Odds ratio	Absolute probability of retreat	Lower confidence Interval	Upper confidence Interval
Reference/Intercept		0.476	0.283	0.092	1.610	0.617	0.481	0.737
Noise tool used in previous event (binary)		-0.468	0.129	0.000	0.626	0.502	0.439	0.565
Projectile tool used in previous event (binary)		-0.262	0.110	0.017	0.770	0.553	0.500	0.606
Number of conditioning actions in the last event (continuous, scaled)		0.088	0.066	0.182	1.092	0.637	0.607	0.667
Number of events in the previous 2 weeks (continuous, scaled)		0.236	0.046	<0.001	1.266	0.671	0.651	0.691
Bear age (continuous, scaled)		-0.512	0.084	<0.001	0.599	0.491	0.450	0.532
Cubs present (binary)		0.574	0.116	<0.001	1.776	0.741	0.695	0.782
Bear activity (categorical)	Travelling: Feeding	-1.472	0.098	<0.001	0.229	0.270	0.233	0.309
	Travelling: Resting	-1.316	0.425	0.002	0.268	0.301	0.158	0.498
	Travelling: Unknown	-0.076	0.156	0.627	0.927	0.599	0.524	0.669

Table 6. Final model set of logistic regression of retreat by grizzly bears at the conclusion of the conditioning event.

Final model set (≤ 2 AIC_c from the top model) predicting grizzly bear retreat at the conclusion of the conditioning event (event response) in Kananaskis Country from 2000 to 2019 with degrees of freedom (df), log likelihood, AIC_c score, delta AIC, model weight, conditional and marginal R^2 values from multivariate logistic regression models. Bear ID was included as a random effect.

Model	Df	Log likelihood	AIC_c	Delta AIC	AIC_c Weight	Conditional R^2	Marginal R^2
Model 1	14	-1155.371	2338.827	0.000	0.272	0.318	0.213
	Event.retreat ~ (Grizzly bear ID) + Number of actions in event + Activity + Age class + Cubs present + Distance from cover + Distance from technician + Approach tool used + Noise tool used + Pursuit tool used						
Model 2	14	-1155.773	2339.632	0.805	0.182	0.319	0.218
	Event.retreat ~ (Grizzly bear ID) + Number of actions in event + Activity + Age class + Cubs present + Distance from cover + Distance from technician + Noise tool used + Projectile tool used + Pursuit tool used						
Model 3	13	-1156.812	2339.697	0.870	0.176	0.314	0.215
	Event.retreat ~ (Grizzly bear ID) + Number of actions in event + Activity + Age class + Cubs present + Distance from cover + Distance from technician + Noise tool used + Pursuit tool used						
Model 4	15	-1155.144	2340.386	1.559	0.125	0.320	0.215
	Event.retreat ~ (Grizzly bear ID) + Number of actions in event + Activity + Age class + Cubs present + Distance from cover + Distance from technician + Approach tool used + Noise tool used + Projectile tool used + Pursuit tool used						

Table 7. Variable attributes predicting probability of grizzly bear retreat in the event analysis logistic regression. Variable attributes from the top model (Table 6) predicting probability of retreat for grizzly bears in Kananaskis Country at the conclusion of the conditioning event (event response) from 2000 to 2019. Columns show variable attributes including both measured percentage and modelled probability of retreat for each variable. Absolute probability of retreat was calculated summing the coefficients for the intercept and each parameter, exponentiating the sum to produce a combined odds ratio and then dividing that value by one plus the odds ratio (OR/(1+OR)).

Variable levels		Coefficient	Standard Error	p-value	Odds ratio	Absolute probability of retreat	Lower confidence Interval	Upper confidence Interval
Reference/Intercept		3.773	0.311	<0.001	43.520	0.978	0.959	0.988
Noise tool used in event (binary)		-0.873	0.179	<0.001	0.418	0.948	0.927	0.963
Approach tool used in event (binary)		-0.231	0.136	0.089	0.794	0.972	0.964	0.978
Pursuit tool used in event (binary)		1.365	0.394	<0.001	3.915	0.994	0.987	0.997
Number of conditioning actions in current event (continuous, scaled)		0.508	0.080	<0.001	1.662	0.986	0.984	0.988
Cubs present (binary)		-0.900	0.148	<0.001	0.407	0.947	0.930	0.959
Distance to vegetative cover (continuous, scaled)		0.447	0.105	<0.001	1.564	0.986	0.982	0.988
Distance from conditioning technician (continuous, scaled)		-0.206	0.068	0.002	0.814	0.973	0.969	0.976
Bear age (categorical)	Adult: Subadult	0.446	0.184	0.015	1.562	0.986	0.979	0.990
	Adult: Juvenile	0.420	0.328	0.200	1.522	0.985	0.972	0.992
Bear activity (categorical)	Travelling: Feeding	-0.069	0.147	0.640	0.933	0.976	0.968	0.982
	Travelling: Resting	0.838	0.748	0.263	2.311	0.990	0.959	0.998
	Travelling: Unknown	-0.859	0.172	<0.001	0.424	0.949	0.929	0.963

Table 8. Variable attributes predicting probability of grizzly bear retreat in the action analysis logistic regression. Univariate models (with bear ID as a random effect) predicting probability of retreat for grizzly bears in Kananaskis Country from 2000 to 2019 in four separate logistic regression analyses comparing deployment methods within four conditioning tool types (action response). Columns show variable attributes including both measured percentage and modelled probability of retreat for each variable. Absolute probability of retreat was calculated summing the coefficients for the intercept and each parameter, exponentiating the sum to produce a combined odds ratio and then dividing that value by one plus the odds ratio (OR/(1+OR)). Reference categories precede each comparison for deployment methods.

	Deployment method	Coefficient	Standard Error	p-value	Number of retreats / total actions	Percentage of retreats	Odds ratio	Probability of retreat	Lower confidence Interval	Upper confidence Interval
Noise conditioning tool Retreat in 926/2314 actions	Reference	1.581	0.127	<0.001	691/830	83.3	4.860	0.829	0.791	0.862
	Dog: human	-0.071	0.124	0.566	1073/1289	83.2	0.931	0.819	0.780	0.852
	Dog: vehicle	-0.085	0.216	0.693	162/195	83.1	0.919	0.817	0.745	0.872
Approach conditioning tool Retreat in 1194/1415 actions	Reference	1.761	0.347	<0.001	62/73	84.9	5.818	0.853	0.747	0.920
	Human: vehicle	-0.133	0.335	0.692	1132/1342	84.4	0.875	0.836	0.725	0.908
Projectile conditioning tool Retreat in 1504/1715	Reference	2.110	0.160	<0.001	970/1096	88.5	8.244	0.892	0.858	0.919
	No contact: contact	0.426	0.190	0.025	534/576	92.7	1.532	0.927	0.897	0.948
Pursuit conditioning tool Retreat in 246/264	Reference	2.3484	0.4682	<0.001	97/108	89.8	10.469	0.913	0.807	0.963
	Dog and human: human	1.4333	0.6539	0.0284	149/153	97.4	4.193	0.978	0.924	0.994

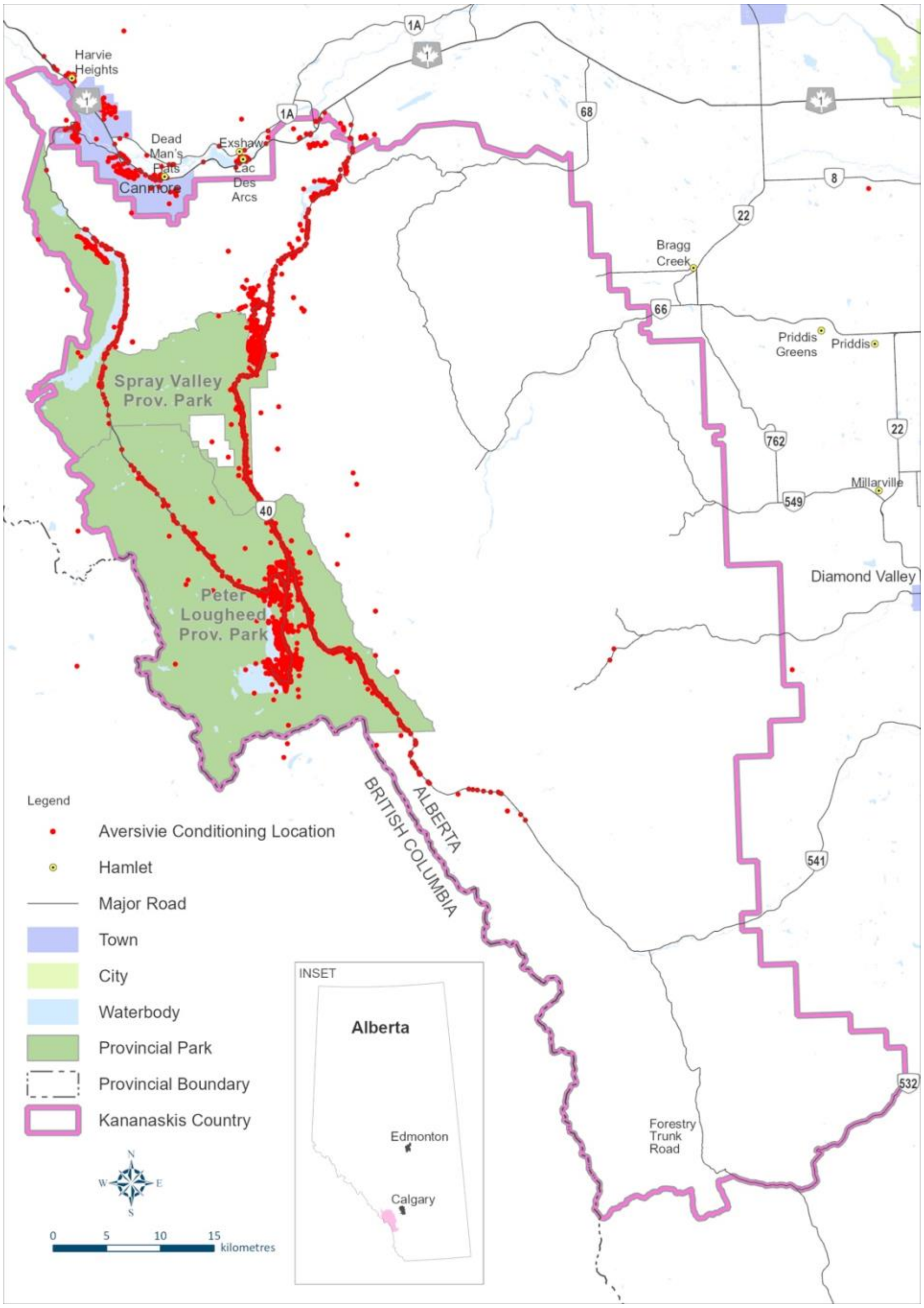

Figure 1. Map of Kananaskis Country.

Showing the boundary of the larger Kananaskis Country management area (pink) and core protected areas of Peter Lougheed and Spray Valley Provincial Parks in green. The inset shows the location of Kananaskis Country relative to major cities in Alberta. Red dots show the locations of aversive conditioning events (n=6,539) on marked and unmarked grizzly bears from 2000 to 2019.

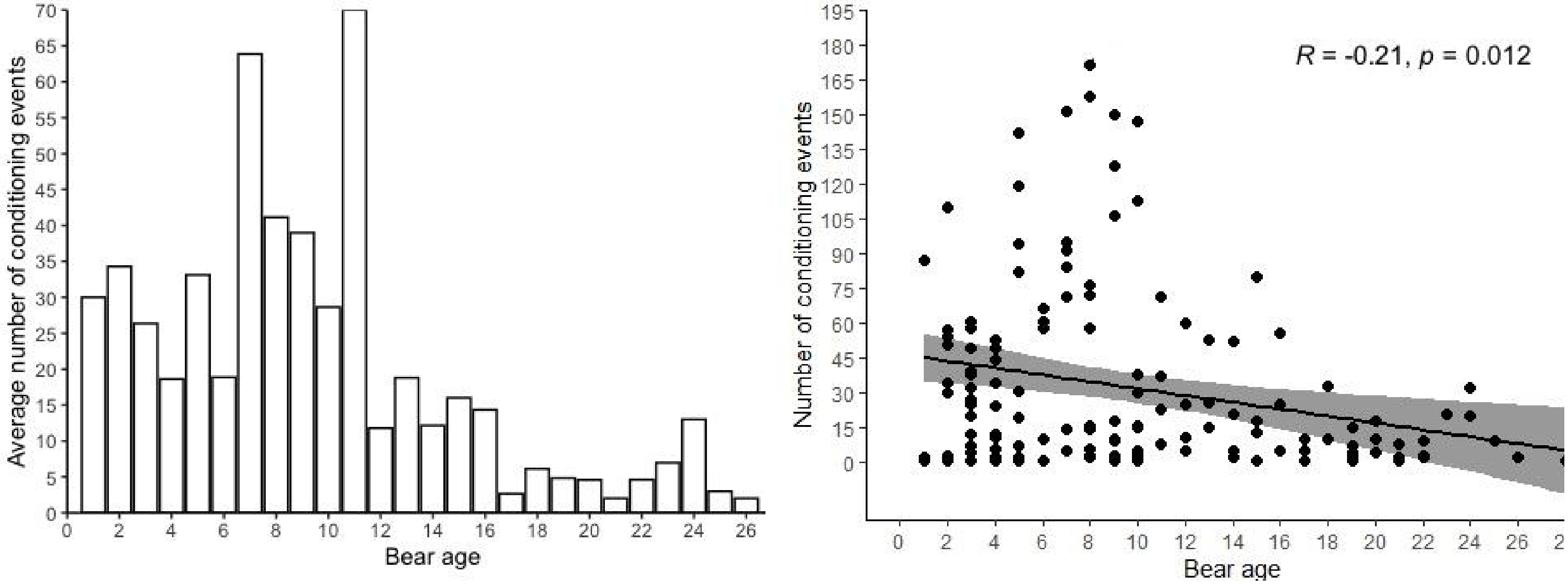

Figure 2. Number of conditioning events by bear age.

Number of conditioning events by bear age in Kananaskis Country, Alberta between 2000 and 2019. Showing (a) the average number of per-individual conditioning actions by bear age, and (b) the total number of conditioning events of marked bears in each age group with a negative correlation between number of conditioning events and bear age (test statistic is shown in the upper right corner of the plot).

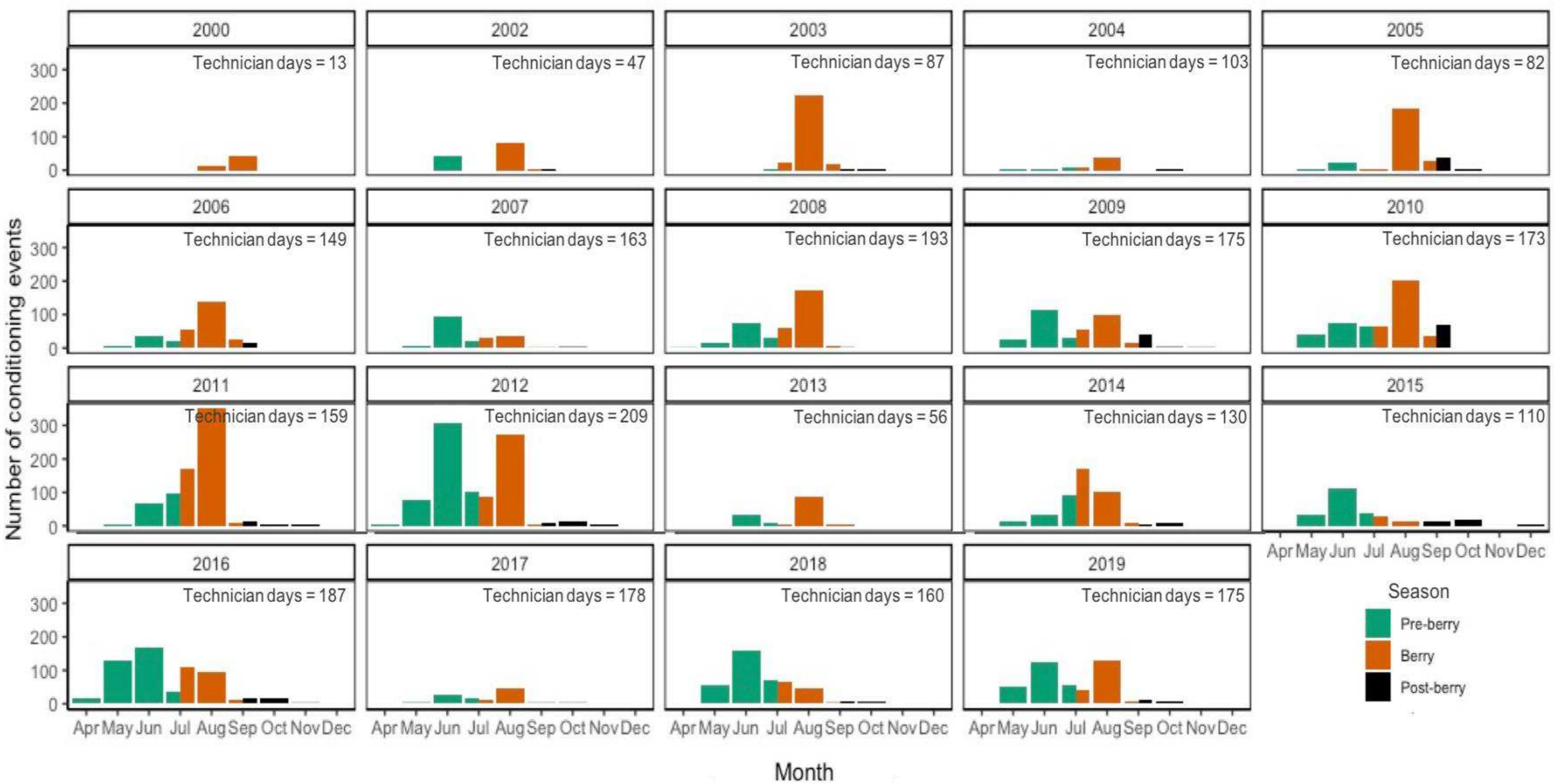

Figure 3. Number of grizzly bear aversive conditioning events per month and year.

Number of grizzly bear aversive conditioning events per month and year in Kananaskis Country from 2000 to 2019. Months are coloured according to natural attractant season relevant to berry-producing shrubs (pre-berry season: April 1 - July 14; berry season: July 15 - September 7; post-berry season: September 8 – December 31).

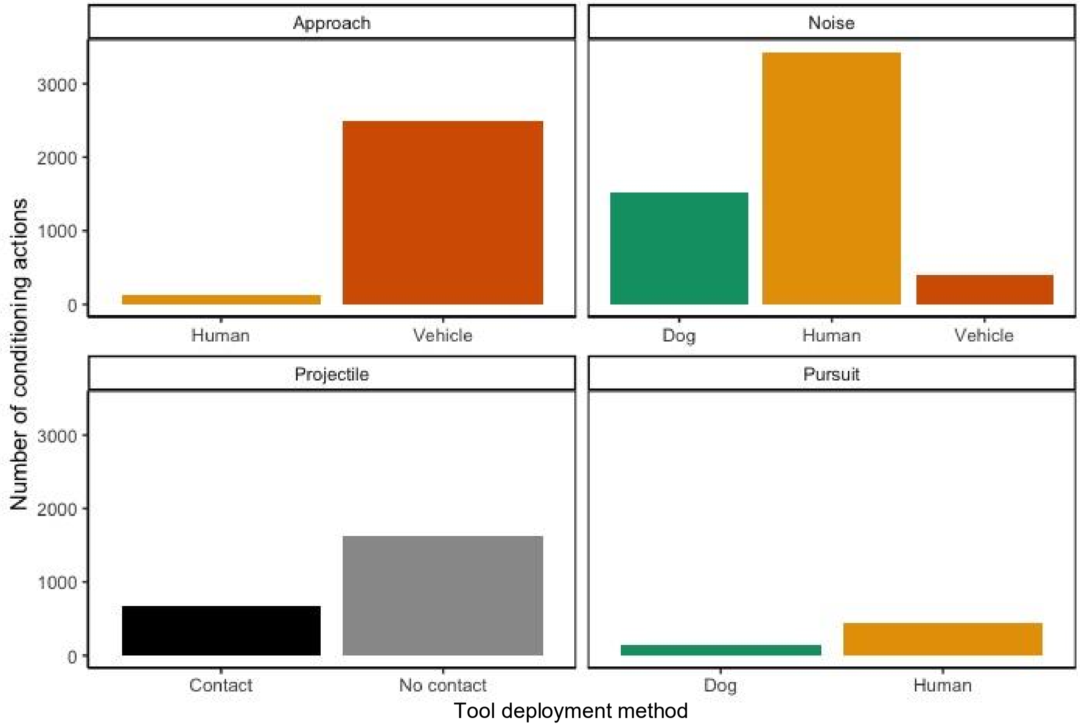

Figure 4. Number of conditioning actions with each deployment method for four conditioning tool types.

Number of conditioning actions with each deployment method for four conditioning tool types, showing deployment method among 10,867 conditioning actions and 6,539 conditioning events on grizzly bears in Kananaskis Country from 2000 to 2019.

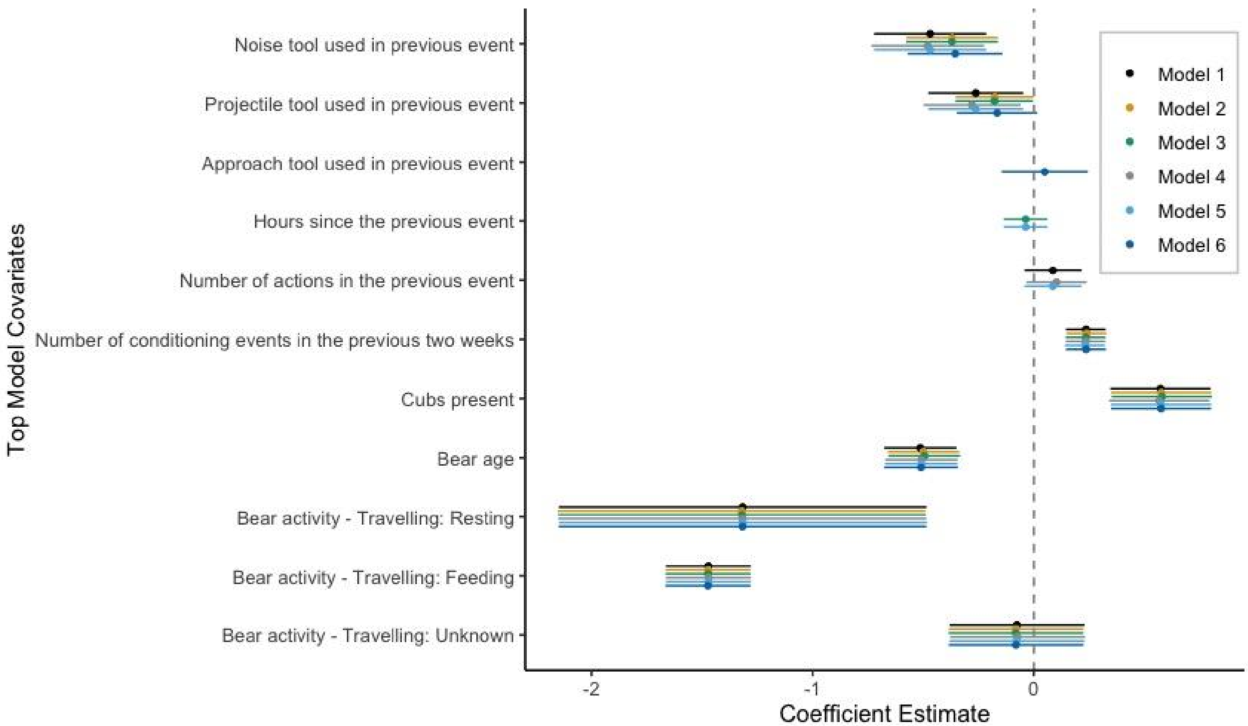

Figure 5. Coefficient estimates for the arrival analysis logistic regression. Coefficient estimates and 95% confidence intervals for the retained multivariate logistic regression models (AIC within 2 units of the top model) predicting grizzly bear retreat on arrival of conditioning technician (arrival response) in Kananaskis Country from 2000 to 2019.

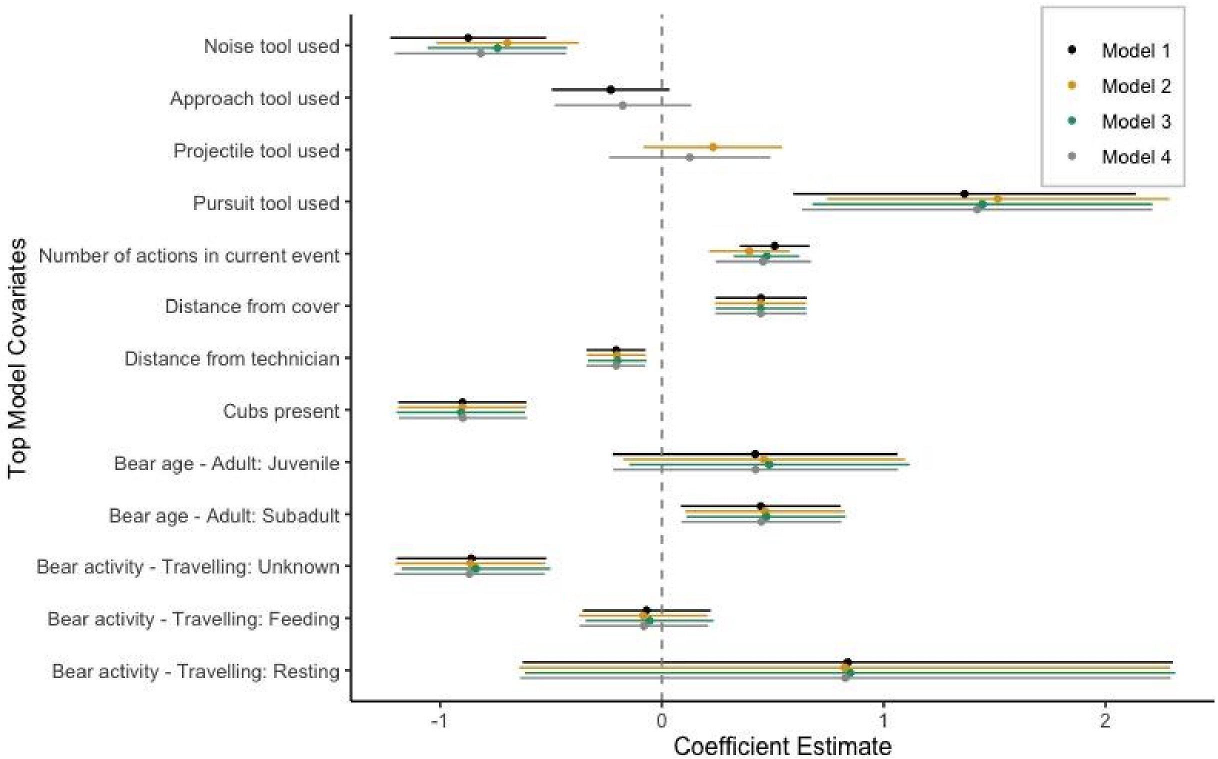

Figure 6. Coefficient estimates for the event analysis logistic regression.
Coefficient estimates and 95% confidence intervals for the retained multivariate logistic regression models (AIC within 2 units of the top model) predicting grizzly bear retreat at the conclusion of the conditioning event (event response) in Kananaskis Country from 2000 to 2019.

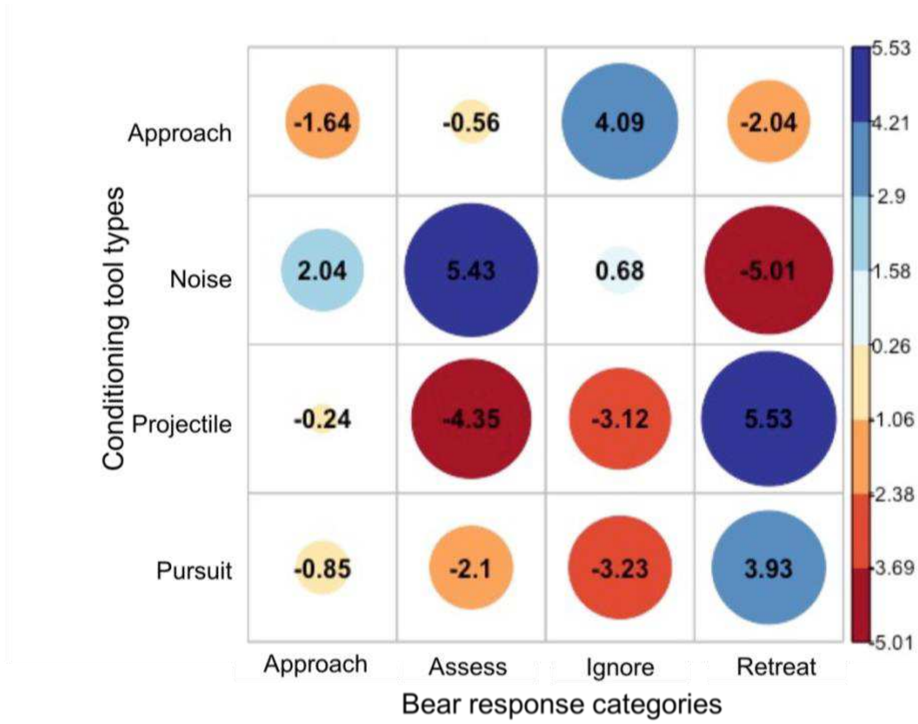

Figure 7. Matrix of Pearson's Chi-square test residuals comparing bear responses to tool types in the action analysis.

Pearson's Chi-square test residuals for comparisons among pairs of conditioning tool types and bear responses in Kananaskis Country from 2000 to 2019. Within the significant complete model ($X^2 = 73.1$, df = 9, p-value < 0.001), positive residuals are blue, negative residuals are red. Scale bar on the right represents the residual value of each pairwise comparison, and circles with numbers are sized relative to the size of residual values of each pairwise comparison. Absolute values > 2.96 correspond to P < 0.05, calculated using a Bonferroni correction.

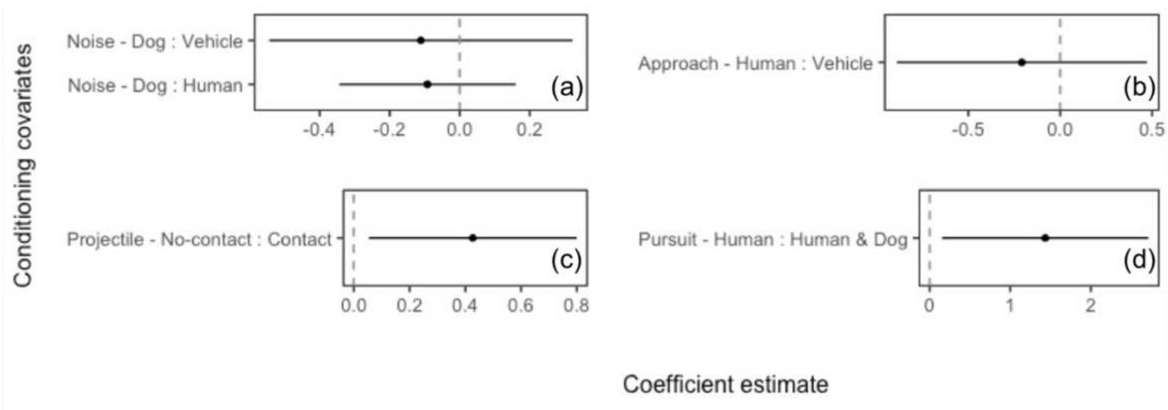

Figure 8. Coefficient estimates for the action analysis logistic regression.

Coefficient estimates and 95% confidence intervals for the univariate logistic regression models predicting grizzly bear retreat from conditioning tool deployment methods within conditioning tool types in the action response in Kananaskis Country from 2000 to 2019. Plots show tool deployment methods within (a) noise conditioning tools, (b) approach conditioning tools (c) projectile conditioning tools and (d) pursuit conditioning tools.

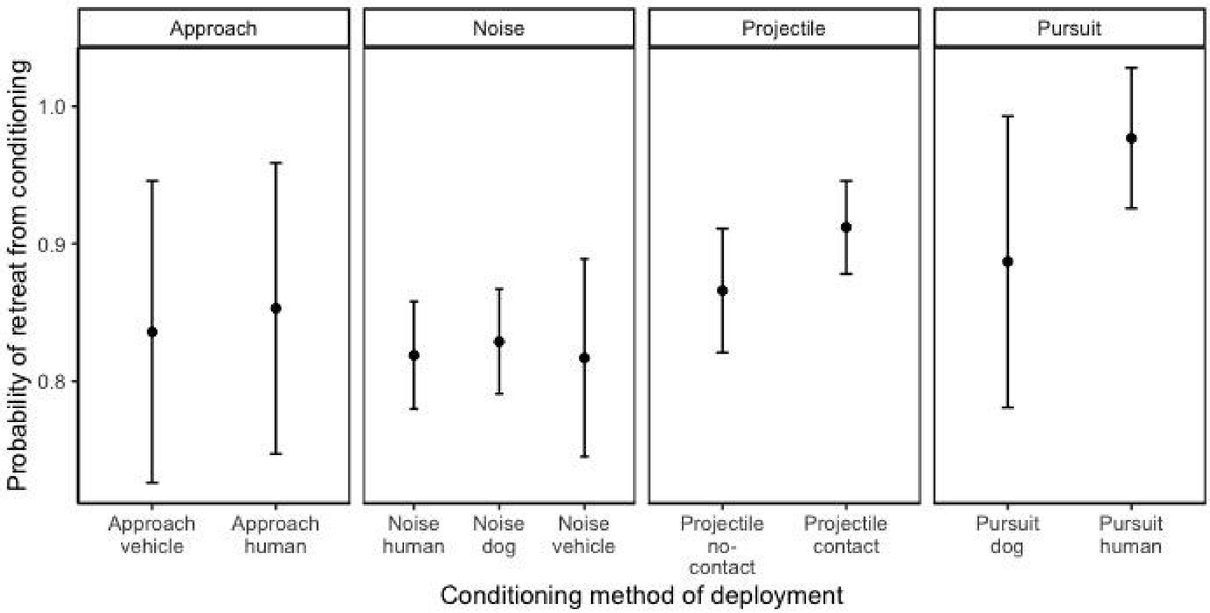

Figure 9. Absolute probabilities of retreat for the action analysis logistic regression. Absolute probabilities of retreat and 95% confidence intervals for each logistic regression analysis predicting grizzly bear retreat from conditioning tool deployment methods within conditioning tool types in the action response in Kananaskis Country from 2000 to 2019.

REFERENCES

Agee, J. D., and C. A. Miller. 2009. Factors Contributing Toward Acceptance of Lethal Control of Black Bears in Central Georgia, USA. Human Dimensions of Wildlife 14:198-205.

Alldredge, M. W., F. E. Buderman, and K. A. Blecha. 2019. Human-Cougar interactions in the wildland-urban interface of Colorado's front range. Ecology and Evolution 9:10415-10431.

Anderson, C., R., M. A. Ternet, and D. S. Moody. 2002. Grizzly Bear-Cattle Interactions on Two Grazing Allotments in Northwest Wyoming. Ursus 13:247-256.

Appleby, R., B. Smith, L. Bernede, and D. Jones. 2017. Utilising aversive conditioning to manage the behaviour of K'gari (Fraser Island) dingoes (Canis dingo). Pacific Conservation Biology 23:335-358.

Atickem, A., L. E. Loe, N. C. Stenseth, and M. Herberstein. 2014. Individual Heterogeneity in Use of Human Shields by Mountain Nyala. Ethology 120:715-725.

Aumiller, L. D., and C. A. Matt. Management of McNeil River State Game Sanctuary for Viewing of Brown Bears, Pages 51-61 *in* Conference Management of McNeil River State Game Sanctuary for Viewing of Brown Bears. February 23-28, 1992.

Bartoń, K. A. 2018. MuMIn: Multi-Model Inference. R package version 1.42.1.

Bates, D., M. Mächler, B. Bolker, and S. Walker. 2015. Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software 67.

Beausoleil, R. 2014. Agency Use of Karelian Bear Dogs for Human-Wildlife Conflict Resolution. International Bear News 23:25-25.

Beausoleil, R. A., and C. W. Lackey. 2015. Responding to human-bear conflict and capture-handling of black bears: a field techniques guide for agency biologists and officers.

Beckmann, J. P., C. W. Lackey, and J. Berger. 2004. Evaluation of deterrent techniques and dogs to alter behavior of "nuisance" black bears. Wildlife Society Bulletin 32:1141-1146.

Bellemain, E., J. E. Swenson, and P. Taberlet. 2006. Mating Strategies in Relation to Sexually Selected Infanticide in a Non-Social Carnivore: the Brown Bear. Ethology 112:238-246.

Bentzen, T. W., R. T. Shideler, and T. M. O'Hara. 2014. Use of stable isotope analysis to identify food-conditioned grizzly bears on Alaska's North Slope. Ursus 25:14-23.

Berger, J. 2007. Fear, human shields and the redistribution of prey and predators in protected areas. Biology Letters 3:620-623.

Blumstein, D. T. 2016. Habituation and sensitization: new thoughts about old ideas. Animal Behaviour 120:255-262.

Bombieri, G., J. Naves, V. Penteriani, N. Selva, A. Fernandez-Gil, J. V. Lopez-Bao, H. Ambarli, C. Bautista, T. Bespalova, V. Bobrov, V. Bolshakov, S. Bondarchuk, J. J. Camarra, S. Chiriac, P. Ciucci, A. Dutsov, I. Dykyy, J. M. Fedriani, A. Garcia-Rodriguez, P. J. Garrote, S. Gashev, C. Groff, B. Gutleb, M. Haring, S. Harkonen, D. Huber, M. Kaboli, Y. Kalinkin, A. A. Karamanlidis, V. Karpin, V. Kastrikin, L. Khlyap, P. Khoetsky, I. Kojola, Y. Kozlow, A. Korolev, N. Korytin, V. Kozsheechkin, M. Krofel, J. Kurhinen, I. Kuznetsova, E. Larin, A. Levykh, V. Mamontov, P. Mannil, D. Melovski, Y. Mertzanis, A. Meydus, A. Mohammadi, H. Norberg, S. Palazon, L. M. Patrascu, K. Pavlova, P. Pedrini, P. Y. Quenette, E. Revilla, R. Rigg, Y. Rozhkov, L. F. Russo, A. Rykov, L. Saburova, V. Sahlen, A. P. Saveljev, I. V. Seryodkin, A. Shelekhov, A. Shishikin, M. Shkvyria, V. Sidorovich, V. Sopin, O. Stoen, J. Stofik, J. E. Swenson, D. Tirski, A. Vasin, P. Wabakken, L. Yarushina, T. Zwijacz-Kozica, and M. M. Delgado. 2019. Brown bear attacks on humans: a worldwide perspective. Sci Rep 9:8573.

Bombieri, G., P. V., M. del Mar Delgado, C. Groff, L. Pedrotti, and K. Jerina. 2021. Towards understanding bold behaviour of large carnivores: the case of brown bears in human-modified landscapes. Animal Conservation.

Bomford, M., and P. H. O'Brien. 1990. Sonic Deterrents in Animal Damage Control: A Review of Device Tests and Effectiveness. Wildlife Society Bulletin 18:411-422.

Bonnell, M. A., and S. W. Breck. 2017. Using resident-based hazing programs to reduce human-coyote conflicts in urban environments. Human-Wildlife Interactions 11:146-155.

Booth, A. L., and D. A. J. Ryan. 2019. A tale of two cities, with bears: understanding attitudes towards urban bears in British Columbia, Canada. Urban Ecosystems 22:961-973.

Can, O. E. 2021. How to design better human wildlife conflict management plans? Forestist 71:118-126.

Can, Ö. E., N. D'Cruze, D. L. Garshelis, J. Beecham, and D. W. Macdonald. 2014. Resolving Human-Bear Conflict: A Global Survey of Countries, Experts, and Key Factors. Conservation Letters 7:501-513.

Clark, J. E., F. T. van Manen, and M. R. Pelton. 2002a. Correlates of Success for On-Site Releases of Nuisance Black Bears in Great Smoky
Mountains National Park. Wildlife Society Bulletin (1973-2006) 30:104-111.

_____. 2002b. Correlates of success for on-site releases of nuisance black bears in Great Smoky Mountains National Park. Wildlife Society Bulletin 30:104-111.

Coleman, T. H., C. C. Schwartz, K. A. Gunther, and S. Creel. 2013. Influence of overnight recreation on grizzly bear movement and behavior in Yellowstone National Park. Ursus 24:101-110.

Conover, M. 2002. Resolving Human – Wildlife Conflicts The Science of Wildlife Damage Management. Lewis Publishers, Boca Raton.

Cotton, W. 2008. Resolving conflicts between humans and the threatened Louisiana black bear. Human-Wildlife Conflicts 2:151-152.

Cox, R., S. E. Baker, D. W. Macdonald, and M. Berdoy. 2004. Protecting egg prey from Carrion Crows: the potential of aversive conditioning. Applied Animal Behaviour Science 87:325-342.

Craven, S., T. Barnes, and G. Kania. 1998. Toward a Professional Position on the Translocation of Problem Wildlife. Wildlife Society Bulletin (1973-2006) 26:171-177.

Domjan, M. 1982. The Principles of Learning and Behavior. 6th ed. edition. Wadsworth, Belmont, Calif. :.

_____. 1996. The Essentials of Conditioning and Learning. 3rd ed. edition. Brooks/Cole Pub. Co., Pacific Grove, Calif. :.

Don Carlos, A. W., A. D. Bright, T. L. Teel, and J. J. Vaske. 2009. Human–Black Bear Conflict in Urban Areas: An Integrated Approach to Management Response. Human Dimensions of Wildlife 14:174-184.

Dorrance, M. J., and L. D. Roy. Aversive conditioning tests of black bears in beeyards failed. 1978.

Edwards, H. A., E. Lebeuf-Taylor, M. Busana, and J. Paczkowski. 2022. Road mitigation structures reduce the number of reported wildlife-vehicle collisions in the Bow Valley, Alberta, Canada. Conservation Science and Practice 4.

Elfström, M., A. Zedrosser, O.-G. Støen, and J. E. Swenson. 2012. Ultimate and proximate mechanisms underlying the occurrence of bears close to human settlements: review and management implications. Mammal Review 44:5-18.

Elmeligi, S., O. T. Nevin, J. Taylor, and I. Convery. 2021. Visitor attitudes and expectations of grizzly bear management in the Canadian Rocky Mountain National Parks. Journal of Outdoor Recreation and Tourism 36.

Festa-Bianchet, M. 2010. Status of the Grizzly Bear (Ursus arctos) in Alberta: Update 2010. Alberta Environment and Parks.

Found, R., E. L. Kloppers, T. E. Hurd, and C. C. St Clair. 2018. Intermediate frequency of aversive conditioning best restores wariness in habituated elk (Cervus canadensis). Plos One 13.

Found, R. B., and C. C. St. Clair. 2016. Behavioural syndromes predict loss of migration in wild elk. Animal Behaviour 115:iii-iv.

_____. 2018. Personality influences wildlife responses to aversive conditioning. The Journal of Wildlife Management 82:747-755.

Fox, J., and S. Weisberg. 2011.

Fuchs, B., K. Yamazaki, A. L. Evans, T. Tsubota, S. Koike, T. Naganuma, and J. M. Arnemo. 2019. Heart rate during hyperphagia differs between two bear species. Biol Lett 15:20180681.

Gabriel, P. O., and R. T. Golightly. 2014. Aversive conditioning of Steller's Jays to improve marbled murrelet nest survival. Journal of Wildlife Management 78:894-903.

Garcia, J., W. G. Hankins, and K. W. Rusiniak. 1974. Behavioral Regulation of the Milieu Interne in Man and Rat. 185:824-831.

Garshelis, D. L., S. Baruch-Mordo, A. Bryant, K. A. Gunther, and K. Jerina. 2017. Is diversionary feeding an effective tool for reducing human–bear conflicts? Case studies from North America and Europe. Ursus 28:31-55.

Garshelis, D. L., M. L. Gibeau, S. Herrero, and Gehrt. 2005. Grizzly Bear Demographics in and around Banff National Park and Kananaskis Country, Alberta. Journal of Wildlife Management 69:277-297.

Gaynor, K. M., C. E. Hojnowski, N. H. Carter, and J. S. Brashares. 2018. The influence of human disturbance on wildlife nocturnality. Science 360:1232-1235.

Gillin, C. M., F. M. Hammond, and C. M. Peterson. 1994. Evaluation of an Aversive Conditioning Technique Used on Female Grizzly Bears in the Yellowstone Ecosystem. Bears: Their Biology and Management 9:503-512.

Gore, M. L., B. A. Knuth, P. D. Curtis, and J. E. Shanahan. 2006. Education programs for reducing American black bear-human conflict: indicators of success? Ursus 17:75-80.

_____. 2007. Factors Influencing Risk Perception Associated with Human–Black Bear Conflict. Human Dimensions of Wildlife 12:133-136.

Goumas, M., V. E. Lee, N. J. Boogert, L. A. Kelley, and A. Thornton. 2020. The Role of Animal Cognition in Human-Wildlife Interactions. Front Psychol 11:589978.

Greene, R. J. 1982. An application of behavioral technology to the problem of nuisance bears. The Psycological Record 32:501 - 511.

Grimes, D. A., and K. F. Schulz. 2002. Descriptive studies: what they can and cannot do. Lancet 359:145-149.

Gunther, K. A., M. A. Haroldson, K. Frey, S. L. Cain, J. Copeland, and C. C. Schwartz. 2004. Grizzly bear–human conflicts in the Greater Yellowstone ecosystem, 1992–2000. Ursus 15:10-22.

Gunther, K. A., K. R. Wilmot, S. L. Cain, T. Wyman, E. G. Reinertson, and A. M. Bramblett. 2018. Managing human-habituated bears to enhance survival, habitat effectiveness, and public viewing. Human-Wildlife Interactions 12:373-386.

Hawley, J. E., S. T. Rossler, T. M. Gehring, R. N. Schultz, P. A. Callahan, R. Clark, J. Cade, and A. P. Wydeven. 2013. Developing a New Shock-Collar Design for Safe and Efficient Use on Wild Wolves. Wildlife Society Bulletin 37:416-422.

Herrero, S. 1976. Conflicts between Man and Grizzly Bears in the National Parks of North America. Bears: Their Biology and Management 3:121-145.

Herrero, S., and A. Higgins. 2003. Human injuries inflicted by bears in Alberta: 1960-98. Ursus 14:44-54.

Herrero, S., T. Smith, T. D. DeBruyn, K. Gunther, and C. A. Matt. 2005. From the field: Brown bear habituation to people - safety, risks, and benefits. Wildlife Society Bulletin 33:362–373.

Hojnowski, C. E. 2017. Spatial and Temporal Dynamics of Wildlife Use of a Human-Dominated Landscape. University of California, Berkeley.

Homstol, L. 2011. Applications of learning theory to human-bear conflict: the efficacy of aversive conditioning and conditioned taste aversion. University of Alberta.

Honda, T., H. Iijima, J. Tsuboi, and K. Uchida. 2018. A review of urban wildlife management from the animal personality perspective: The case of urban deer. Sci Total Environ 644:576-582.

Honda, T., N. Yamabata, H. Iijima, and K. Uchida. 2019. Sensitization to human decreases human-wildlife conflict: empirical and simulation study. European Journal of Wildlife Research 65.

Honeyman, J. 2007. Bow Valley bear hazard assessment report. Karelian Bear Shepherding Institute of Canada.

_____. 2008. A retrospective evaluation of the effectiveness of aversive conditioning on grizzly bears in Peter Lougheed Provincial Park, Alberta, Canada., Royal Roads University.

Hopkins, J. B. H., S. , R. T. Shideler, K. A. Gunther, C. C. Schwartz, and S. T. Kalinowski. 2010. A proposed lexicon of terms and concepts for human–bear management in North America. Ursus 21:154–168.

Hosmer, D. W., and S. Lemeshow. 2000. Applied Logistic Regression, Second Edition. Second Edition edition. John Wiley & Sons, United States of America.

Huffman, J. 2010. New Jersey Bear Aversive Conditioning Report. Northeast Wildlife DNA Laboratory, East Stroudsburg University.

Human-Bear Conflicts Expert Team of the IUCN SSC Bear Specialist Group. 2019a. Approaches to Human-Bear Conflict Management.

_____. 2019b. Principles of Human-Bear Conflict Reduction. Human-Bear Conflicts Expert Team of the IUCN SSC Bear Specialist Group.

Hunt, C. 2008. WRBI BEAR SHEPHERDING GUIDELINES. Wind River Bear Institute.

Johnson, H. E., D. L. Lewis, S. A. Lischka, and S. W. Breck. 2018a. Assessing ecological and social outcomes of a bear-proofing experiment. Journal of Wildlife Management 82:1102-1114.

Johnson, H. E., D. L. Lewis, T. L. Verzuh, C. F. Wallace, R. M. Much, L. K. Willmarth, S. W. Breck, and C. Bieber. 2018b. Human development and climate affect hibernation in a large carnivore with implications for human carnivore conflicts. Journal of Applied Ecology 55:663-672.

Kloppers, E. L., C. C. St Clair, and T. E. Hurd. 2005. Predator-resembling aversive conditioning for managing habituated wildlife. Ecology and Society 10.

Kubo, T., and Y. Shoji. 2014. Spatial tradeoffs between residents' preferences for brown bear conservation and the mitigation of human-bear conflicts. Biological Conservation 176:126-132.

_____. 2016. Demand for bear viewing hikes: Implications for balancing visitor satisfaction with safety in protected areas. Journal of Outdoor Recreation and Tourism 16:44-49.

LaBarge, L. R., A. T. L. Allan, C. M. Berman, R. A. Hill, and S. W. Margulis. 2022. Cortisol metabolites vary with environmental conditions, predation risk, and human shields in a wild primate, Cercopithecus albogularis. Horm Behav 145:105237.

Lackey, C. W., S. W. Breck, B. F. Wakeling, and H. B. White. 2018. Human-Black Bear Conflicts: A Review of Common Management Practices. Human-Wildlife Interactions Monographs 2:1-68.

Lajeunesse, G. 2023. Two programs for use of aversive conditioning to manage bold urban coyotes. University of Alberta, Edmonton, Alberta.

Laskin, D. N., G. J. McDermid, S. E. Nielsen, S. J. Marshall, D. R. Roberts, and A. Montaghi. 2019. Advances in phenology are conserved across scale in present and future climates. Nature Climate Change 9:419-425.

Leigh, J., and M. J. Chamberlain. 2008. Effects of aversive conditioning on behavior of nuisance Louisiana black bears. Human-Wildlife Conflicts 2:175-182.

Lennox, R. J., A. J. Gallagher, E. G. Ritchie, and S. J. Cooke. 2018. Evaluating the efficacy of predator removal in a conflict-prone world. Biological Conservation 224:277-289.

Lüdecke, D., D. Makowski, M. S. Ben-Shachar, I. Patil, P. Waggoner, B. M. Wiernik, V. Arel-Bundock, R. m. Thériault, and M. Jullum. 2021. performance: An R Package for Assessment, Comparison and Testing of Statistical Models. Journal of Open Source Software 6.

Madison, J. S. 2008. Yosemite National Park: the continuous evolution of human–black bear conflict management. Human-Wildlife Conflicts 2:160-167.

Marchini, S., K. M. P. M. B. Ferraz, A. Zimmermann, T. Guimarães-Luiz, R. Morato, P. L. P. Correa, and D. W. Macdonald. 2019. Planning for Coexistence in a Complex Human-Dominated World. Pages 414-438 *in* Human–Wildlife Interactions.

Mattson, D. J., S. Herrero, R. G. Wright, and C. M. Pease. 1996. Science and Management of Rocky Mountain Grizzly Bears. Conservation Biology 10:1013-1025.

Mazur, R. L. 2010. Does Aversive Conditioning Reduce Human–Black Bear Conflict? Journal of Wildlife Management 74:48-54.

McCarthy, T. M., and R. J. Seavoy. 1994. Reducing Nonsport Losses Attributable to Food Conditioning: Human and Bear Behavior Modification in an Urban Environment. Bears: Their Biology and Management 9:75-84.

McClelland, C. J. R., N. C. Coops, S. P. Kearney, A. C. Burton, S. E. Nielsen, and G. B. Stenhouse. 2020. Variations in grizzly bear habitat selection in relation to the daily and seasonal availability of annual plant-food resources. Ecological Informatics 58.

McCullough, D. R. 1982. Behavior, Bears, and Humans. Wildlife Society Bulletin 10:27-33.

Morehouse, A. T., and M. S. Boyce. 2017. Evaluation of intercept feeding to reduce livestock depredation by grizzly bears. Ursus 28.

Morehouse, A. T., T. A. Graves, N. Mikle, and M. S. Boyce. 2016. Nature vs. Nurture: Evidence for Social Learning of Conflict Behaviour in Grizzly Bears. Plos One 11.

Morehouse, A. T., C. Hughes, N. Manners, J. Bectell, and J. Tigner. 2021. Dealing With Deadstock: A Case Study of Carnivore Conflict Mitigation From Southwestern Alberta. Frontiers in Conservation Science 2.

Morehouse, A. T., J. Tigner, and M. S. Boyce. 2018. Coexistence with Large Carnivores Supported by a Predator-Compensation Program. Environ Manage 61:719-731.

Mueller, C., S. Herrero, and M. L. Gibeau. 2004. Distribution of Subadult Grizzly Bears in Relation to Human Development in the Bow River Watershed, Alberta. Ursus 15:33-47.

Munro, R. H. M., S. E. Nielsen, M. H. Price, G. B. Stenhouse, and M. S. Boyce. 2006. Seasonal And Diel Patterns Of Grizzly Bear Diet And Activity In West-Central Alberta. Journal of Mammalogy 87:1112–1121.

Myers, P. J., and J. K. Young. 2018. Consistent individual behavior: evidence of personality in black bears. Journal of Ethology 36:117-124.

Nakagawa, S., P. C. D. Johnson, and H. Schielzeth. 2017. The coefficient of determination R(2) and intra-class correlation coefficient from generalized linear mixed-effects models revisited and expanded. J R Soc Interface 14.

Nielsen, S. E., A. B. Shafer, M. S. Boyce, and G. B. Stenhouse. 2013. Does learning or instinct shape habitat selection? PLoS One 8:e53721.

Northrup, J. M., J. Pitt, T. B. Muhly, G. B. Stenhouse, M. Musiani, M. S. Boyce, and N. Pettorelli. 2012a. Vehicle traffic shapes grizzly bear behaviour on a multiple-use landscape. Journal of Applied Ecology 49:1159-1167.

Northrup, J. M., G. B. Stenhouse, M. S. Boyce, M. Gompper, and A. Vanak. 2012b. Agricultural lands as ecological traps for grizzly bears. Animal Conservation 15:369-377.

Ohta, U., M. Jusup, T. Mano, H. Tsuruga, and H. Matsuda. 2012. Adaptive management of the brown bear population in Hokkaido, Japan. Ecological Modelling 242:20-27.

Ordiz, A., O.-G. Støen, S. Saebø, V. Sahlén, B. E. Pedersen, J. Kindberg, J. E. Swenson, and J. Rhodes. 2013. Lasting behavioural responses of brown bears to experimental encounters with humans. Journal of Applied Ecology 50:306-314.

Ordiz, A., O.-G. Støen, S. Sæbø, J. Kindberg, M. Delibes, and J. E. Swenson. 2012. Do bears know they are being hunted? Biological Conservation 152:21-28.

Otto, T. E., and G. J. Roloff. 2015. Black bear exclusion fences to protect mobile apiaries. Human–Wildlife Interactions 9:78–86.

Penteriani, V., M. D. M. Delgado, M. Krofel, K. Jerina, A. Ordiz, F. Dalerum, A. Zarzo-Arias, and G. Bombieri. 2018. Evolutionary and ecological traps for brown bears Ursus arctos in human-modified landscapes. Mammal Review 48:180-193.

Penteriani, V., M. D. M. Delgado, F. Pinchera, J. Naves, A. Fernandez-Gil, I. Kojola, S. Harkonen, H. Norberg, J. Frank, J. M. Fedriani, V. Sahlen, O. G. Stoen, J. E. Swenson, P. Wabakken, M. Pellegrini, S. Herrero, and J. V. Lopez-Bao. 2016. Human behaviour can trigger large carnivore attacks in developed countries. Sci Rep 6:20552.

Penteriani, V., J. V. López-Bao, C. Bettega, F. Dalerum, M. d. M. Delgado, K. Jerina, I. Kojola, M. Krofel, and A. Ordiz. 2017. Consequences of brown bear viewing tourism: A review. Biological Conservation 206:169-180.

Petelle, M. B., D. E. McCoy, V. Alejandro, J. G. A. Martin, and D. T. Blumstein. 2013. Development of boldness and docility in yellow-bellied marmots. Animal Behaviour 86:1147-1154.

Petracca, L. S., J. L. Frair, G. Bastille-Rousseau, J. E. Hunt, D. W. Macdonald, L. Sibanda, and A. J. Loveridge. 2019. The effectiveness of hazing African lions as a conflict mitigation tool: implications for carnivore management. Ecosphere 10.

Pienaar, E. F., D. Telesco, and S. Barrett. 2015. Understanding people's willingness to implement measures to manage human-bear conflict in Florida. Journal of Wildlife Management 79:798-806.

Powell, D. M., and M. C. Gartner. 2011. Applications of Personality to the Management and Conservation of Nonhuman Animals. Pages 185-199 *in* From Genes to Animal Behavior.

Proctor, M. F., B. N. McLellan, G. B. Stenhouse, G. Mowat, C. T. Lamb, and M. S. Boyce. 2020. Effects of roads and motorized human access on grizzly bear populations in British Columbia and Alberta, Canada. Ursus 2019.

Rauer, G., P. Kaczensky, and F. Knauer. 2003. Experiences with aversive conditioning of habituated brown bears in Austria and other European countries. Ursus (Knoxville) 14:215-224.

Reich, H. Is a Bite Worse Than a Bark? The Best Use Method of Karelian Bear Dogs in Hazing of Black Bears in Nevada, *in* Conference Is a Bite Worse Than a Bark? The Best Use Method of Karelian Bear Dogs in Hazing of Black Bears in Nevada.

Ronconi, R. A., and C. C. St. Clair. 2005. Efficacy of a radar-activated on-demand system for deterring waterfowl from oil sands tailings ponds. Journal of Applied Ecology 43:111-119.

Sahlen, V., A. Ordiz, J. E. Swenson, and O. G. Stoen. 2015. Behavioural differences between single scandinavian brown bears (Ursus arctos) and females with dependent young when experimentally approached by humans. PLoS One 10:e0121576.

Sakurai, R., S. K. Jacobson, and G. Ueda. 2013. Public perceptions of risk and government performance regarding bear management in Japan. Ursus 24:70-82.

Schaefer, R. J., D. Moyles, S. McDonald, M. Cervelli, and D. Beck. 2021. Relocation of habituated black bears in the Klamath Mountains of California: an adaptive management case study. California Fish and Wildlife Journal 107:202-212.

Schmidt, R. H., and R. M. Timm. Bad dogs: why do coyotes and other canids become unruly. 2007.

Skrbinšek, A. M., and M. Krofel. 2014. Progress report for the pilot action: defining, preventing, and reacting to problem bear behaviour in the Alpine region. University of Ljubljana, Biotechnical Faculty.

Smith, T. S., S. Herrero, and T. D. DeBruyn. 2005. Alaskan Brown Bears, Humans, and Habituation. Ursus 16:1-10.

Snijders, L., N. M. Thierij, R. Appleby, C. C. St. Clair, and J. Tobajas. 2021. Conditioned Taste Aversion as a Tool for Mitigating Human-Wildlife Conflicts. Frontiers in Conservation Science 2.

Spencer, R. D., R. A. Beausoleil, and D. A. Martorello. 2007. How Agencies Respond to Human–black Bear Conflicts: A Survey of Wildlife Agencies in North America. Ursus 18:217-229.

Stankowich, T. 2008. Ungulate flight responses to human disturbance: A review and meta-analysis. Biological Conservation 141:2159-2173.

Starling, M. J., N. Branson, P. C. Thomson, and P. D. McGreevy. 2013. Age, sex and reproductive status affect boldness in dogs. Vet J 197:868-872.

Stenhouse, G. 1982. Bear Detection and Deterrent Study. NWT Wildlife Services.

Steyaert, S. M. J. G., M. Leclerc, F. Pelletier, J. Kindberg, S. Brunberg, J. E. Swenson, and A. Zedrosser. 2016. Human shields mediate sexual conflict in a top predator. Proceedings of the Royal Society B 283.

Thompson, P. R., M. A. Lewis, M. A. Edwards, and A. E. Derocher. 2022. Time-dependent memory and individual variation in Arctic brown bears (Ursus arctos). Mov Ecol 10:18.

Timm, R. M., R. O. Baker, and J. R. Bennett. Coyote Attacks: An Increasing Suburban Problem. 2004.

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

Treves, A., and L. Naughton-Treves. 2005. Evaluating lethal control in the management of human–wildlife conflict. *in* R. Woodroffe, S. Thirgood, and A. Rabinowitz, editors. People and Wildlife: Conflict or Coexistence? Cambridge University Press, London.

Wilson, S. M., M. J. Madel, D. J. Mattson, J. M. Graham, and T. Merrill. 2006. Landscape conditions predisposing grizzly bears to conflicts on private agricultural lands in the western USA. Biological Conservation 130:47-59.

Woolridge, D. R., and P. Belton. 1980. Natural and Synthesized Aggressive Sounds as Polar Bear Repellents. Bears: Their Biology and Management 4:85-91.

APPENDIX 1

Supplementary material for Chapter 1

Supplementary Material 1. A summary of 40 papers on aversive conditioning (AC) and hazing management programs for bears available in the peer-reviewed and gray literature.

Programs are categorized by the management landscape AC and hazing took place on, how programs were labelled, conflict behaviours targeted by programs, and how success was measured. Papers were compiled between 2017 and 2023 and include programs conducted from 1976 to 2022 (full references provided in Supplementary Material 4).

Authors	Species	Year	Country	Landscape	Program name	Conflict behaviour targeted	Success metric
Dorrance and Gunson	*Ursus americanus*	1976	Canada	Agricultural	AC and hazing	Depredation	Behavioural
Gunson	*Ursus americanus*	1980	Canada	Agricultural	Relocation	Depredation	Behavioural
Woolridge and Belton	Multiple	1980	Canada	Industrial	AC	Food conditioning	Spatial
Greene	Multiple	1982	USA	Parks and protected areas	AC	Nuisance behaviour	Spatial
Stenhouse	*Ursus maritimus*	1982	Canada	Industrial	Deterrent use	Anthropogenic food seeking	Temporal
Miller	Multiple	1983	Canada	Captive	Deterrent use	Aggression toward humans	Behavioural
Stenhouse and Cattet	*Ursus maritimus*	1984	Canada	Industrial	Deterrent use	Anthropogenic food seeking	Temporal
Hunt	Multiple	1984	USA	Captive	AC	Aggression toward humans	Behavioural
Derocher and Miller	*Ursus maritimus*	1986	Canada	Industrial	AC	Anthropogenic food seeking	Temporal
Compuheat Services	*Ursus maritimus*	1984	Canada	Industrial	AC	Anthropogenic food seeking	Undefined
Rogers	*Ursus americanus*	1986	USA	Various	Relocation	Nuisance behaviour	Spatial
Miller	*Ursus maritimus*	1987	Canada	Industrial	Deterrent use	Aggression toward humans	Spatial
Wooding	*Ursus americanus*	1988	USA	Agricultural	Relocation	Depredation	Behavioural

Dalle-Molle and Van Horn	Multiple	1989	USA	Parks and protected areas	AC	Nuisance behaviour	Undefined
Aumiller and Matt	*Ursus arctos*	1992	USA	Parks and protected areas	AC	Defensive behaviour	Behavioural
Gillin et al.	*Ursus arctos*	1994	USA	Parks and protected areas	AC	Nuisance behaviour	Behavioural
McCarthy and Seavoy	*Ursus americanus*	1994	USA	Urban	AC	Food conditioning and habituation	Temporal
Herrero and Higgins	Multiple	1998	North America	Various	Bear spray	Undesirable behaviour	Behavioural
Schirokauer and Boyd	Multiple	1998	USA	Parks and protected areas	Hazing and AC	Nuisance behaviour	Spatial
Anderson et al.	*Ursus arctos*	2002	USA	Agricultural	AC and hazing	Depredation	Behavioural
Clark et al.	*Ursus americanus*	2002	USA	Parks and protected areas	On-site release	Nuisance behaviour	Management reports
Rauer et al.	*Ursus arctos*	2003	Austria	Agricultural	AC	Habituation	Behavioural
Weaver	*Ursus americanus*	2004	USA	Urban	Hard release	Nuisance behaviour	Spatial
Beckmann et al.	*Ursus americanus*	2004	USA	Urban	AC	Nuisance behaviour	Temporal
Morrison	Multiple	2005	Canada	Parks and protected areas	AC	Habituation	Behavioural
Brabyn et al.	*Ursus americanus*	2005	Canada	Urban	AC	Nuisance behaviour	Spatial
Hopkins et al.	*Ursus americanus*	2007	USA	Parks and protected areas	AC and hazing	Food conditioning	Undefined
Smith et al.	Multiple	2008	USA	Various	Deterrent use	Undesirable behaviour	Behavioural
Madison	*Ursus americanus*	2008	USA	Parks and protected areas	AC	Nuisance behaviour	Management reports
Leigh and Chamberlain	*Ursus americanus*	2008	USA	Urban	AC	Nuisance behaviour	Spatial
Honeyman	*Ursus arctos*	2008	Canada	Parks and protected areas	AC	Habituation	Temporal
Mazur	*Ursus americanus*	2010	USA	Parks and protected areas	AC	Food conditioning	Behavioural
Huffman	*Ursus americanus*	2010	USA	Urban	AC	Nuisance behaviour	Temporal
Homstol	*Ursus americanus*	2011	Canada	Urban	AC	Habituation	Behavioural
Madonia et al.	*Ursus americanus*	2011	USA	Urban	AC	Nuisance behaviour	Spatial

Lewis et al.	*Ursus americanus*	2012	USA	Urban	Hazing	Food conditioning and approaching humans	Behavioural
Comeau	*Ursus americanus*	2013	USA	Urban	AC	Nuisance behaviour	Spatial
Homstol et al.	*Ursus americanus*	2015	Canada	Various	AC	Habituation	Undefined
Ashcraft and Krebs	*Ursus americanus*	2018	USA	Parks and protected areas	Hazing	Negative behavioural patterns	Management reports
White et al.	*Ursus americanus*	2022	USA	Parks and protected areas	Relocation	Conflict behaviour	Spatial

Supplementary Material 2. Reported success of aversive conditioning and hazing management programs on bears. A summary of 31 papers on AC and hazing for bears compiled by species, success metrics used, whether program success was measured, and whether success was measured qualitatively (through trends over time) or quantitatively (through descriptive statistics).

Species studied	How conflict behaviour was categorized	Success metric	Program success reported	Success measured quantitatively or qualitatively	Number of papers
Ursus americanus	Depredation	Behavioural	No	Qualitative	1
Ursus americanus	Depredation	Behavioural	Yes	Qualitative	2
Ursus americanus	Food conditioning	Behavioural	Yes	Quantitative	1
Ursus americanus	Food conditioning	Undefined	Yes	Quantitative	1
Ursus americanus	Food conditioning and habituation	Behavioural	Yes	Qualitative	1
Ursus americanus	Food conditioning and habituation	Temporal	No	Quantitative	1
Ursus americanus	Habituation	Behavioural	Yes	Quantitative	1
Ursus americanus	Habituation	Undefined	Yes	Quantitative	1
Ursus americanus	Nuisance behaviour	Management	Yes	Qualitative	3
Ursus americanus	Nuisance behaviour	Spatial	No	Qualitative	3
Ursus americanus	Nuisance behaviour	Spatial	Yes	Qualitative	1
Ursus americanus	Nuisance behaviour	Spatial	Yes	Quantitative	3
Ursus americanus	Nuisance behaviour	Temporal	Yes	Quantitative	2
Ursus arctos	Defensive behaviour	Behavioural	Yes	Qualitative	1
Ursus arctos	Depredation	Behavioural	Yes	Qualitative	1
Ursus arctos	Habituation	Behavioural	Yes	Qualitative	1
Ursus arctos	Habituation	Temporal	Yes	Qualitative	1
Ursus arctos	Nuisance behaviour	Behavioural	Yes	Qualitative	1
Ursus maritimus	Aggression toward humans	Spatial	Yes	Quantitative	1
Ursus maritimus	Anthropogenic food seeking	Temporal	No	Quantitative	2
Ursus maritimus	Anthropogenic food seeking	Temporal	Yes	Quantitative	1
Ursus maritimus	Anthropogenic food seeking	Undefined	Yes	Qualitative	1

Supplementary Material 3. A summary of literature reviewing and discussing human bear conflict management interventions available in the peer-reviewed and gray literature.

Papers are categorized by the source and type of publication (full references provided in Supplementary Material 4).

Authors	Source	Type	Year	Title
Miller	Thesis	na	1980	Behavioral and physiological characteristics of grizzly and polar bears and their relation to bear repellents
McCullough	Journal article	Review	1982	Behavior, Bears, and Humans
Clarkson	Conference	Tool review	1989	The Twelve Gauge Shotgun: A Bear Deterrent and Protection Weapon
Heuer	Government report	Review	1993	A Literature Review of Causes, symptoms and Management options with an Emphasis on Aversive Conditioning
Gillin et al.	Journal article	Opinion	1997	Management of bear-human conflicts using laika dogs
Smith et al.	Journal article	Review	2000	Review of methods to reduce livestock depredation II. Aversive conditioning, deterrents and repellents
Witmer and Whittaker	Conference	Review	2001	Dealing with nuisance and depredating black bears
Gore	Journal article	Review	2004	Comparison of Intervention Programs Designed to Reduce Human-Bear Conflict: A Review of the Literature
Can et al.	Journal article	Review	2004	Resolving Human-Bear Conflict: A Global Survey of Countries, Experts, and Key Factors
Shivik	Journal article	Review	2006	Tools for the Edge: What's New for Conserving Carnivores
Green et al.	Conference	Bibliography	2007	An annotated bibliography of aversive conditioning with a focus on black bear
Spencer et al.	Journal article	Review	2007	How Agencies Respond to Human–black Bear Conflicts: A Survey of Wildlife Agencies in North America
Beausoleil	Newsletter	Tool review	2014	Agency Use of Karelian Bear Dogs for Human-Wildlife Conflict Resolution
Skrbinšek and Krofel	Government report	Review	2014	Progress report for the pilot action: defining, preventing, and reacting to problem bear behaviour in the Alpine region
Miller	Journal article	Review	2016	Effectiveness of Contemporary Techniques for Reducing Livestock Depredations by Large Carnivores
Lackey et al.	Journal article	Review	2018	Human–Black Bear Conflicts: A Review of Common Management Practices
Snijders et al.	Journal article	Systematic map	2019	Effectiveness of animal conditioning interventions in reducing human-wildlife conflict: a systematic map protocol
Khorozyan and Walter	Journal article	Review	2020	Variation and conservation implications of the effectiveness of anti-bear interventions

Supplementary Material 4. Aversive conditioning and hazing literature referred to in SM1, SM2, and SM3.

Anderson, C., R., M. A. Ternet, and D. S. Moody. 2002. Grizzly Bear-Cattle Interactions on Two Grazing Allotments in Northwest Wyoming. Ursus 13:247-256.

Ashcraft, R. T., and R. A. Krebs. 2018. Assessment Of Black Bear (Ursus Americanus) Response Behavior To Human Presence In Yellowstone National Park Through Observational Study. The Ohio Journal of Science.

Aumiller, L. D., and C. A. Matt. 1994. Management of McNeil River State Game Sanctuary for Viewing of Brown Bears. Bears: Their Biology and Management 9:51-61.

Beausoleil, R. 2014. Agency Use of Karelian Bear Dogs for Human-Wildlife Conflict Resolution. International Bear News 23:25-25.

Beausoleil, R. A., and C. W. Lackey. 2015. Responding to human-bear conflict and capture-handling of black bears: a field techniques guide for agency biologists and officers.

Beckmann, J. P., C. W. Lackey, and J. Berger. 2004. Evaluation of deterrent techniques and dogs to alter behavior of "nuisance" black bears. Wildlife Society Bulletin 32:1141-1146.

Brabyn, N., L. Homstol, and T. Hamilton. 2005. Whistler Black Bear Aversive Conditioning and Monitoring Project. BC Conservation Corps.

Can, O. E. 2021. How to design better human wildlife conflict management plans? Forestist 71:118-126.

Can, Ö. E., N. D'Cruze, D. L. Garshelis, J. Beecham, and D. W. Macdonald. 2014. Resolving Human-Bear Conflict: A Global Survey of Countries, Experts, and Key Factors. Conservation Letters 7:501-513.

Canada, C. S. 1986. Infra-red Detection and Acoustic Deterrent Study. Government of the Northwest Territories, Yellowknife.

Clark, J. E., F. T. van Manen, and M. R. Pelton. 2002. Correlates of success for on-site releases of nuisance black bears in Great Smoky Mountains National Park. Wildlife Society Bulletin 30:104-111.

Clarkson, P. L. The Twelve Guage Shotgun: A Bear Deterrent and Protection Weapon. Northwest Territories Department of Renewable Resources, 6-10 April 1987 1989.

Comeau, N. A. 2013. Evaluation of Two Methods of Aversive Conditioning on Nuisance Activity Levels of New Hampshire Black Bear. Plymouth State Universi.

Conover, M. 2002. Resolving Human – Wildlife Conflicts The Science of Wildlife Damage Management. Lewis Publishers, Boca Raton.

Dalle-Molle, J. L., and J. C. Van Horn. Bear-People Conflict Management in Denali National Park. Northwest Territories Department of Renewable Resources, 6-10 April 1987 1989.

Derocher, A. E., and J. S. Miller. 1986. Bear Deterrent Study. Government of the Northwest Territories, Yellowknife, NWT.

Domjan, M. 1996. The Essentials of Conditioning and Learning. 3rd ed. edition. Brooks/Cole Pub. Co., Pacific Grove, Calif. :.

Dorrance, M. J., and J. R. Gunson. 1976. An Evaluation of Non-Lethal Control Techniques for Problem Black Bears in Beeyards. Edmonton.

Dorrance, M. J., and L. D. Roy. Aversive conditioning tests of black bears in beeyards failed. 1978.

Garcia, J., W. G. Hankins, and K. W. Rusiniak. 1974. Behavioral Regulation of the Milieu Interne in Man and Rat. 185:824-831.

Gillin, C. M., I. Chestin, P. Semchenkov, and J. Claar. 1997. Management of Bear-Human Conflicts Using Laika Dogs. Bears: Their Biology and Management 9:133-137.

Gillin, C. M., F. M. Hammond, and C. M. Peterson. 1994. Evaluation of an Aversive Conditioning Technique Used on Female Grizzly Bears in the Yellowstone Ecosystem. Bears: Their Biology and Management 9:503-512.

Gore, M. L. 2004. Comparison of Intervention Programs Designed to Reduce Human-Bear Conflict: A Review of the Literature. ecommons.cornell.edu.

Green, J. G., S. L. McMullin, and J. A. Parkhurst. 2007. An annotated bibliography of aversive conditioning with a focus on black bear.

Greene, R. J. 1982. An application of behavioral technology to the problem of nuisance bears. The Psycological Record 32:501 - 511.

Gunson, J. R. 1980. Black Bear - Beeyard Management In Alberta. open.alberta.ca.

Herrero, S., and A. Higgins. 1998. Field use of capsicum spray as a bear deterrent. Ursus.

Heuer, K. 1993. A Literature Review of Causes, symptoms and Management options with an Emphasis on Aversive Conditioning. Canadian Parks Service, Banff, Alberta.

Homstol, L. 2011. Applications of learning theory to human-bear conflict: the efficacy of aversive conditioning and conditioned taste aversion. University of Alberta.

Homstol, L., C. Edwards, and C. Hunt. Using aversive conditioning to keep bears wary of traffic. Proceedings of the 12th Western Black Bear Workshop. May …… 2015 2015.

Honeyman, J. 2008. A retrospective evaluation of the effectiveness of aversive conditioning on grizzly bears in Peter Lougheed Provincial Park, Alberta, Canada., Royal Roads University.

Hopkins, J. B., S. Lisius, V. Seher, S. W. Breck, and N. Lance. Evaluation of a new aversive conditioning treatment to manage black bears in Yosemite National Park. Proceedings of the 9th Western Black Bear Workshop. April 19-22, 2006 2006.

Huffman, J. 2010. New Jersey Bear Aversive Conditioning Report. Northeast Wildlife DNA Laboratory, East Stroudsburg University.

Hunt, C. 1983. Vol 2. Deterrents and aversive conditioning, an Annotated bibliography. University of Montana, Missoula, Montana.

_____. 1984. Vol. 1. Behavioral responses of bears to tests of repellents deterrents and aversive conditioning. University fo Montana, Montana.

Khorozyan, I., and M. Waltert. 2020. Variation and conservation implications of the effectiveness of anti-bear interventions. Scientific Reports 10:9.

Lackey, C. W., S. W. Breck, B. F. Wakeling, and H. B. White. 2018. Human-Black Bear Conflicts: A Review of Common Management Practices. Human-Wildlife Interactions Monographs 2:1-68.

Leigh, J., and M. J. Chamberlain. 2008. Effects of aversive conditioning on behavior of nuisance Louisiana black bears. Human-Wildlife Conflicts 2:175-182.

Lewis, L. L., D. Dawes, and P. Mooney. 2012. The Use of an Electronic Control Device in Wildlife Management: A Case Series. Proceedings of the Vertebrate ….

Madison, J. S. 2008. Yosemite National Park: the continuous evolution of human–black bear conflict management. Human-Wildlife Conflicts 2:160-167.

Madonia, M. J., A. S. Zellner, J. Huffman, K. Burguess, P. C. Carr, and E. Skirta. Evaluation of aversive conditioning using satelite collars on black bears in New Jersey. North Carolina Wildlife Resources Commission, 2011.

Mazur, R. L. 2010. Does Aversive Conditioning Reduce Human–Black Bear Conflict? Journal of Wildlife Management 74:48-54.

McCarthy, T. M., and R. J. Seavoy. 1994. Reducing Nonsport Losses Attributable to Food Conditioning: Human and Bear Behavior Modification in an Urban Environment. Bears: Their Biology and Management 9:75-84.

McCullough, D. R. 1982. Behavior, bears, and humans. Wildlife Society Bulletin.

Miller, G. D. 1980. Behavioral and physiological characteristics of grizzly and polar bears and their relation to bear repellents. scholarworks.umt.edu.

_____. 1983. Responses of captive grizzly and polar bears to potential repellents. Bears: Their Biology and Management.

_____. 1987. Field tests of potential polar bear repellents. Bears: Their Biology and Management 7:383-390.

Morrison, H. 2004. Results of Aversive Conditioning on 17 Radio-Collared Problem Bears, 1991 œ 2004. Parks Canada Document.

Rauer, G., P. Kaczensky, and F. Knauer. 2003. Experiences with aversive conditioning of habituated brown bears in Austria and other European countries. Ursus (Knoxville) 14:215-224.

Rogers, L. L. 1986. Effects Of Translocation Distance On Frequency Of Return By Adult Black Bears. Wildlife Society Bulletin 14:76-80.

Schirokauer, D. W., and H. M. Boyd. 1998. Bear-Human Conflict Management in Denali National Park and Preserve, 1982-94. Ursus 10:395-403.

Shivik, J. A. 2006. Tools for the edge: what's new for conserving carnivores. BioScience.

Skrbinšek, A. M., and M. Krofel. 2014. Progress report for the pilot action: defining, preventing, and reacting to problem bear behaviour in the Alpine region. University of Ljubljana, Biotechnical Faculty.

Smith, M. E., J. D. C. Linnell, J. Odden, and J. E. Swenson. 2000. Review of methods to reduce livestock depredation II. Aversive conditioning, deterrents and repellents. Acta Agriculturae Scandinavica Section a-Animal Science 50:304-315.

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

Snijders, L., A. L. Greggor, F. Hilderink, and C. Doran. 2019. Effectiveness of animal conditioning interventions in reducing human-wildlife conflict: a systematic map protocol. Environmental Evidence 8.

Spencer, R. D., R. A. Beausoleil, and D. A. Martorello. 2007. How Agencies Respond to Human–black Bear Conflicts: A Survey of Wildlife Agencies in North America. Ursus 18:217-229.

Stenhouse, G. 1982. Bear Detection and Deterrent Study. NWT Wildlife Services.

Stenhouse, G., and M. Cattet. 1984. Bear Detection and Deterrent Study. NWT Wildlife Service.

Weaver, H. W. 2004. Biometric Analysis and Aversive Conditioning of Black Bears in Southern West Virginia. West Virginia University, Morgantown, West Virginia.

White, J. P., W. H. Stiver, M. K. Steinberg, and J. R. Cissell. 2022. Comparing management techniques used on conflict American black bears in Great Smoky Mountains National Park. Ursus 33:7.

Witmer, G. W., and D. G. Whittaker. Dealing With Nuisance And Depredating Black Bears. May 2-5, 2000 2001.

Wooding, J. B., N. L. Hunter, and T. S. Hardisky. 1988. Trap and release apiary-raiding black bears.

Woolridge, D. R., and P. Belton. 1980. Natural and Synthesized Aggressive Sounds as Polar Bear Repellents. Bears: Their Biology and Management 4:85-91.

Supplementary Material 5. List of locations where aversive conditioning actions took place in Kananaskis Country between 2000 and 2019.

Location	Count	Percentage
Roadside	2608	40
Campground	518	8
Day use	274	4
Trail	150	4
Golf course	113	3
Residential rural	109	3
Facility	101	3
Green space	87	2
Other	69	2
Ski hill	2	0
Unknown	2508	38