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Capstone Project

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CAPSTONE PROJECT

by

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CHAPTER 1. LITERATURE REVIEW

Livestock Guardian Dogs as a Tool for Large Carnivore Conservation

Introduction

Retaliatory killings of wildlife as a response to livestock depredation contributes to population declines of large carnivores and in some cases to species becoming listed as vulnerable, endangered, or critically endangered (Ivaşcu & Biro, 2020; Spencer et al. 2020). Human-wildlife conflict is a reality faced by farmers, and incidents are becoming more frequent as climate change, increasing human populations, and urbanization cause humans and wildlife to share increasingly crowded areas (Lieb et al. 2021; Wakoli et al. 2023). Most human-carnivore conflict results from wildlife killing livestock and farmers killing wildlife in response (Potgieter et al. 2015). Financially compensating producers for livestock loss doesn't end retaliatory killings or change farmers' negative views towards predators (Potgieter et al. 2015). Lethal practices are still used around the world, as many livestock producers believe lethal control to be practical and economical (Spencer et al. 2020). However, lethal control methods only provide short term solutions as predator populations often recover quickly due to immigration and improved reproductive success (Saitone & Bruno, 2020; van Bommel & Johnson, 2012). Additionally, lethal control measures can have various, unforeseen cascading effects on prey and small predator species in the local ecosystem (Treves & Naughton-Treves, 2005). Recent conservation efforts, as well as policies such as the United States' ban on poisoning carnivores, led many farmers to turn to the use of livestock guardian dogs (LGDs) to protect their stock (Rust et al. 2013; van Bommel & Johnson, 2012).

A source of traditional ecological knowledge (TEK), shepherds across Eurasia have used LGDs for thousands of years (Ivaşcu & Biro, 2020; Kinka & Young, 2018). Like many sources of TEK, the use of LGDs has a wealth of anecdotal evidence, with gaps where quantified knowledge is lacking. Quantifying TEK is vital, as traditional knowledge is often more accurate than western management practices (Oviedo et al. 2004) There are studies that evaluate the success of LGDs at reducing rates of depredation and economic assessments of running LGDs on farms (Gonzalez et al. 2012; Rust et al. 2013). Much of the research regarding LGDs has been collected through interviews and questionnaires, whereas more recent studies aim to quantify their use and effectiveness (Gonzalez et al. 2012; Potgieter et al. 2015; Vielmi & Boitani, 2018). While many claim LGDs are an environmentally friendly and nonlethal method to deter livestock depredation, there remains a lack of empirical evidence suggesting that the use of LGDs increases and aids in the conservation of large carnivore populations (Ivaşcu & Biro, 2020; Zingaro et al. 2018). This review aims to evaluate the use of LGDs as a tool for reducing human-wildlife conflict and for carnivore conservation, as well as identify areas where more knowledge is necessary to deepen our understanding of LGDs as a method for reducing human-wildlife conflict.

History

Originating in the Middle East, LGDs have been employed in parts of Eurasia for nearly six millennia to reduce livestock loss to predators including wolves, bears, and lynx (Dawydiak & Sims, 2019; Ivaşcu & Biro, 2020; Kinka & Young, 2018). LGDs consist of multiple breeds of domestic dogs, bred specifically to live full time with livestock to protect them from depredation, theft, or injury (Kinka & Young, 2019; van Bommel & Johnson, 2014). Shepherds selectively bred dogs for protectiveness, attentiveness, and trustworthiness (Ivaşcu & Biro, 2020). Physical characteristics also play a part in dog selection; in parts of Europe puppies with big paws and heads are preferred as they will likely become large adults, while a black mouth is said to be an indication of aggression and bravery (Ivaşcu & Biro, 2020). Training and bonding the dog to their charges is essential for successful guardians. Puppies are kept with stock to bond and develop affiliative behavior that will lead them to choose to stay with and protect the stock, while adult dogs are often used to train and mentor puppies and younger dogs (Ivaşcu & Biro, 2020; van Bommel & Johnson, 2012). These behavioral and physical traits led to the widespread use of LGDs for nearly 6,000 years (Rust et al. 2013).

Despite their long history, LGD use over the last 200 years decreased in accordance with the decline of predator populations (Gehring et al. 2010; van Bommel & Johnson, 2012). However, their use has seen a resurgence in the last few decades due to conservation efforts for large carnivores (Gehring et al. 2010; Rust et al. 2013). This resurgence is not only occurring where LGDs originated, but in places such as North America, Africa, and South America (Gonzalez et al. 2012; Kinka & Young, 2018; Potgieter et al. 2015). More than half of sheep ranchers in the western US use LGDs, and Colorado saw an increase from 25 farmers using LGDs to 159 in a seven-year time span (Andelt & Hopper, 2000; Dawydiak & Sims, 2019). In projects located in South America and Africa that provided LGDs to farms, farmers reported the dogs were effective in both reducing predation and altering negative views of wildlife (Gonzalez et al. 2012; Potgieter et al. 2015). With thousands of years of anecdotal evidence and recent research that supports this oral history, LGDs are considered an effective tool in mitigating livestock depredation.

What Makes an Effective LGD?

There are many factors that contribute to how well an LGD protects its charges. Several studies investigating LGD behavior and efficacy have found that age, more so than sex, is a critical factor in LGD success (Kinka & Young, 2018; Zingaro et al. 2018). Older dogs spend more time in close proximity to stock, and while this is usually attributed to experience and attentiveness, it may be affected by limited mobility due to age (Zingaro et al. 2018). Anecdotally, dogs over two years old perform better than their younger counterparts (Kinka & Young, 2018). Recent research demonstrates a difference in LGD behavior before and after two years (van Bommel & Johnson 2012). Andelt & Hopper (2000) found that most farmers surveyed claimed their dogs' effectiveness improved over time.

Beyond the consensus that age is crucial to LGD performance, there are conflicting results regarding how breed influences LGD success. Rigg (2001) claims that certain breeds of LGD are more successful at deterring wolves than others, while Kinka & Young (2018), in an experiment that simulated a wolf encounter, found that initial responses to threats differed among breed, but overall behavior was constant over time. Many experts are adamant that breeds other than livestock guardian dogs are not suited to guard livestock, but mixed breed dogs are successfully used by the Navajo tribe and Patagonian herders (Black & Green, 1985; Gonzalez et al. 2012). While it appears that LGD breeds are equally effective in reducing depredation rates, some breeds are more likely to wander, harass livestock or wildlife, and act aggressively towards unfamiliar people (Dawydiak & Sims, 2019). Additionally, different breeds mature at different ages. Most dogs begin working around 1 to 2 years of age, while some breeds may be ready at 6 months (Rigg, 2001). Therefore, managers and landowners should consider their specific needs and location, such as endangered or threatened wildlife and public access, when choosing which breed of LGD to employ.

Perhaps more important than age and breed is the training that LGDs receive from their handlers. Farmers regard training and bonding as essential to a successful LGD (Zingaro et al. 2018). In fact, research suggests that training and handling are more important than breed when it comes to an effective guardian (Coppinger & Coppinger, 2002). It is crucial for the dog to bond with the stock its protecting because proximity to stock is essential for preventing depredation (Ivaşcu & Biro, 2020; Zingaro et al. 2018). The first 2 years of an LGD's life is a critical time for training as young, immature dogs can develop undesirable behaviors such as harassing or killing stock and wildlife, roaming, and failing to bond to stock (van Bommel & Johnson, 2023). Training can also be used to correct dogs exhibiting unwanted behaviors (Potgieter et al. 2015; Zingaro et al. 2018).

In addition to age, breed, and experience, another extrinsic factor that contributes to LGDs' efficacy is the number of livestock they are protecting. To be successful, an adequate number of dogs must be present based on the predator load, size of operation, and herd size (van Bommel & Johnson, 2023). LGDs may not cease depredation when the stock to dog ratio exceeds 100 to 1 (van Bommel & Johnson, 2012). Multiple LGDs can outnumber predators that hunt in groups, such as wolves, as well as provide different behavioral techniques that may increase success over multiple predator species (Urbigkit & Urbigkit, 2010). More information is needed to provide an in-depth analysis of the dynamics between herd size, predator load, and number of LGDs necessary (Andelt & Hopper, 2000).

Efficacy of LGDs in Preventing Livestock Predation

A growing body of literature suggests that LGDs are one of the most effective methods of preventing human-wildlife conflict (Leib et al. 2021). Many studies that aim to quantify the success of LGDs investigate whether the dogs reduce rates of livestock depredation. While they don't eliminate depredation entirely, they do significantly reduce livestock loss to predators (Andelt & Hopper, 2000). LGDs have been found to successfully decrease livestock losses (Potgieter et al. 2015; Rust et al. 2013); however, these rates vary between studies (Gavagnach &

Ben-Ami, 2023). Scientists report that LGDs reduce livestock loss anywhere from 11-100% (Ivaşcu & Biro, 2020). Farmers in Africa saw a reduction in livestock loss after introducing LGDs to their productions (Potgieter et al. 2015). In Argentina, 100% of farmers surveyed reported a reduction in predation rates after adding LGDs to their operations, while 89% of farmers without LGDs in the same region reported an increase in predation (Gonzalez et al. 2012). In addition to providing evidence that LGDs are effective in preventing livestock depredation, these studies also support the claim that LGDs are an effective tool in preventing human-wildlife conflict.

Economic Assessment

In addition to studying LGD efficacy, some researchers have investigated the economic costs and benefits of running LGDs with livestock, and the few studies of economic evaluations of LGDs have conflicting results. The costs of acquiring and maintaining LGDs can exceed the money saved through lowered predation rates due to vet bills, feed, training, and other expenses such as adequate fencing to keep LGDs contained (Saitone & Bruno, 2020). In some regions, LGDs are too expensive for farmers to afford (Gonzalez et al. 2012). LGDs have been found to be economically beneficial in some circumstances and should be considered on an individual basis (Saitone & Bruno, 2020). Rust et al (2013) reported that LGDs save farmers nearly $3,000 USD, and Andelt & Hopper (2000) claim LGDs contribute value to the local economy through money saved in reduced livestock loss. Another study reported the initial costs of acquiring an LGD are returned after 1 to 3 years (van Bommel & Johnson, 2012). The lack of extensive economic assessments on the use of LGDs, combined with discrepancies in the few studies that have made such assessments, leaves a gap for further study. To aid producers, a more comprehensive evaluation of the economic costs and benefits of LGDs is necessary, however, it is widely shown that these dogs provide additional benefits that extend beyond agriculture and into conservation work.

Do LGDs Benefit Carnivore Conservation?

Across the globe, LGDs are proving to be successful at reducing livestock depredation in a variety of geographic locations with a range of predators. In the United States, LGDs face black bears (*Ursus americanus*), mountain lions (*Puma concolor*), wolves (*Canis lupus*), and coyotes (*Canis latrans*) (Andelt & Hopper, 2000; Kinka & Young, 2018). In Australia, the biggest concern for livestock are dingoes (*Canis familiaris dingo*) (van Bommel & Johnson, 2012). Wolves, brown bears (*Ursus arctos arctos*), and lynx (*Lynx lynx*) threaten stock in Eurasia (Ivaşcu & Biro, 2020). In Patagonia, LGDs protect stock from large cats, including mountain lions and the endangered Andean cat (*Leopardus jacobita*) (Gonzalez et al. 2012). LGDs in Africa deter jackals (*Canis aureus*), hyenas (*Hyaenidae*), leopards (*Panthera pardus*), and cheetahs (*Acinonyx jubatus*) (Potgieter et al. 2015). This research suggests that LGDs are versatile and can reduce livestock depredation across a wide taxonomic range of carnivores.

Some studies claim LGDs are environmentally friendly and that they aid in carnivore conservation (Ivaşcu & Biro, 2020; Lieb et al. 2021; van Bommel & Johnson, 2012). However, there exists concern regarding the ecological effects of LGDs, especially when it comes to lethal interactions with target and nontarget wildlife species (Kinka et al. 2021; Lieb et al. 2021). For one, LGDs are not completely nonlethal and on occasion will kill wildlife (Potgieter et al. 2015). While LGDs are capable of chasing and killing wildlife, they typically use indirect cues to deter predators (Lieb et al. 2021). These cues include barking, scent-marking, and eating afterbirth during livestock birthing periods (Lieb et al. 2021). LGDs in Australia frequently communicate through olfactory cues with dingoes, suggesting that the predators recognize boundaries created by LGDs (van Bommel & Johnson, 2017). Additionally, LGD handlers can employ training techniques to put an end to behaviors that negatively impact wildlife (Kinka et al. 2021). However, just as LGDs are capable of learning and changing their behavior through training, wildlife may also adjust to the presence of LGDs, and learn to take stock while LGDs are present (van Bommel & Johnson, 2023). The ability of LGDs and wildlife to learn and adjust their behavior are variables that add complexity to carnivore conservation in an agricultural context. People and livestock bring even more nuance to the mechanisms at play when running LGDs in carnivore habitat. An additional variable that complicates conservation in agricultural lands is that ranches often encompass private and public lands that may fall under the jurisdiction of government agencies as well as private landowners (Sheridan, 2001).

Studies that investigate the conservation implications of LGDs often use surveys to establish people's perceptions of LGDs and wildlife (Gonzalez et al. 2012; Potgieter et al. 2015; Rust et al. 2013). Conservationists in Romania previously held negative opinions of LGDs, but recently have been coming to view them in a positive light (Ivaşcu & Biro, 2020). In Patagonia, 88% of farmers surveyed reported that they no longer kill wildlife after obtaining LGDs (Gonzalez et al. 2012). One of the predators often involved in human-wildlife conflict in Patagonia is the endangered Andean cat, which is predominately threatened by goat herders (Gonzalez et al. 2012). With a decline in retaliatory killings, this study suggests that LGDs play an important role in the conservation of the Andean cat (Gonzalez et al. 2015). In Namibia, all the participating subsistence farmers reported an end to retaliatory killings post LGD introduction (Potgieter et al. 2015). Farmers in South Africa reported an increase of predator tolerance by 79%, as well as a perceived increase in local cheetah populations (Rust et al. 2013). The results of these studies suggest LGDs have a positive influence on predator populations.

While these reports aid in furthering our initial understanding of the relationship between LGDs and carnivore conservation, interviews and surveys are often plagued by false reporting and recall bias (Kinka & Young, 2019). These studies offer insight into how LGDs influence the farmers' perceptions of predators, but it is necessary to quantify the relationship between LGDs and carnivores to best understand the implications of LGD use in the context of carnivore conservation.

There are a few preliminary studies that aim to quantify how LGDs influence the conservation of large carnivores. Large carnivores showed avoidance of areas with sheep bands (a flock of sheep grazed in open range, while accompanied by humans and LGDs), with bears showing a possible long-term avoidance (Kinka et al. 2021). The authors recognize that their results do not provide conclusive evidence of LGDs aiding in carnivore conservation, but they acknowledge that altering movement of predators is a preferable alternative to lethal methods of preventing stock depredation (Kinka et al. 2021). The first study to test whether LGDs exclude predators from landscapes in Africa stated that if they are to be considered beneficial to carnivore conservation, LGDs cannot reduce the use of land by predators (Spencer et al. 2020). This study found no difference in predator presence on farms with and without LGDs, indicating that LGDs are a conservation tool that aids both people and wildlife (Spencer et al. 2020). To further corroborate this information, another study found that environmental factors were more influential on carnivore behavior than LGDs (Bromen et al. 2019). Their results suggest that LGDs can effectively protect livestock without having a detrimental effect on the space use of carnivores (Bromen et al. 2019).

Conclusion

The behavioral and physical traits of these dogs, plus thousands of years of oral history and recent empirical research, illustrate how LGDs successfully reduce rates of livestock depredation by predators. The reduction in depredation insinuates that LGDs are in some way affecting the movement and behavior of predators by deterring them from hunting livestock (van Bommel & Johnson, 2016). This reduction in depredation rates also correlates with a reduction in retaliatory killings (Gonzalez et al. 2012). Reducing human-wildlife conflict, such as limiting incidents of retaliatory killings, is an essential factor in carnivore conservation (Potgieter et al. 2015). Therefore, LGDs influence on predators, such as displacement, may be the best option for carnivore conservation when compared to lethal methods (Kinka et al. 2021).

LGDs ability to alter farmers perceptions of wildlife in a short amount of time has beneficial implications for large carnivores (Gonzalez et al. 2012, Rust et al. 2013). It is well documented that this altered perception corresponds to a reduction in retaliatory killings, which benefits predator populations (Potgieter et al. 2015). This altered perception may even lead farmers to invest more time into carnivore conservation practices on their land. Landowners are essential to carnivore conservation as they manage large tracts of undeveloped land (Gehring et al. 2010). Due to limited funds and resources, conservation efforts often rely on private landowners' voluntary involvement (Reiter et al. 2021). While Rust et al. (2013) reported a perceived increase in cheetah populations after implementation of LGDs, it remains unclear whether LGDs in Namibia are positively influencing cheetah numbers. More research is necessary to establish if carnivore numbers increase in correspondence with LGD presence.

Studies show LGDs can protect stock without completely excluding predators from the landscape, demonstrating that populations of carnivores, specifically endangered ones, can persist in farmed areas (Bromen et al. 2019). This provides evidence that LGDs aid in carnivore conservation. However, LGDs are shown to cause avoidance in some predators, and the length of avoidance for some predators remains unknown (Kinka et al. 2021). Therefore, it is important to understand the dynamics that influence carnivore movement and behavior where LGDs are present.

Concerns regarding the negative ecological effects of LGDs are valid, with reports of LGDs chasing and harassing wildlife, wandering, and acting aggressively towards people and domestic animals (Gavagnach & Ben-Ami, 2023; Lieb et al. 2021). However, there is limited research on the ecological impacts of LGDs (Kinka et al. 2021). Additionally, handlers can train dogs to correct unwanted behaviors (van Bommel & Johnson, 2016). The ability of LGDs to quickly learn and make decisions poses a myriad of opportunities to evaluate how training techniques can be implemented to aid in the conservation of large carnivores.

As urbanization expands worldwide, it results in habitat fragmentation, which is a critical driver of biodiversity loss (Laurance et al. 2007). Farms and ranches can serve as critical corridors and habitat patches for wildlife, especially at-risk species (Reiter et al. 2021). Current research suggests that LGDs don't significantly alter movement of large carnivores (Spencer et al. 2020). More information regarding LGD presence and its influence on carnivores is imperative for carnivore conservation. In Namibia and Patagonia, further research will provide crucial information about the status of endangered species like the cheetah and Andean cat (Gonzalez et al. 2012, Potgieter et al. 2015). Future studies could provide an understanding of how LGDs impact smaller, nontarget predators, as well as populations of wild herbivores. While initial studies support the idea that LGDs aid in large carnivore conservation, there is still much we don't understand about how LGDs impact wildlife. More research will provide clarity into the dynamics and relationship between livestock guardian dogs and wildlife conservation and give us a deeper understanding of the role LGDs play in carnivore conservation.

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CHAPTER 2. GRANT PROPOSAL

Assessing the impacts of livestock guardian dogs on nontarget wildlife species

Abstract

Globally, conflict between people and wildlife is increasing, often with lethal repercussions for wildlife when they prey on livestock. Non-lethal techniques, such as livestock guardian dogs (LGDs), are becoming popular worldwide. Research demonstrates that LGDs successfully reduce livestock depredation by carnivores and reduce rates of retaliatory killings of target predators. This indicates that LGDs are beneficial to the conservation of large carnivores, but the scope of their ecological effects on nontarget wildlife species are not fully assessed or understood. This study aims to address this knowledge gap and provide crucial information regarding how LGDs influence surrounding wildlife communities. I will assess the influence that LGDs have on the behavior and occupation of local wildlife species through a camera trap study located on ranches with and without LGDs in northwestern Colorado. The camera traps will collect data on the presence of both target (large carnivore) and nontarget wildlife species, quantifying frequency and duration of visit as well as group size. I hypothesize that LGDs will alter wildlife behavior without excluding them from the landscape, and that the effects of LGDs will differ between species. This study will provide valuable insights as one of the first studies to assess the ecological impacts of LGDs on both large and small predators, as well as prey species.

Introduction

Objective

The goal of this study is to better understand the ecological impacts of livestock guardian dogs (LGDs) on nontarget wildlife species, or species that the dogs aren’t specifically bred and trained to protect livestock against, such as mesopredators and herbivores. I propose to conduct a camera trap study located in northwestern Colorado in order to quantify the ecological effects LGDs have on the behavior and occupation of nontarget wildlife species.

Questions and hypotheses

Question: How do LGDs modify the occupation and behavior of nontarget predators and herbivores?

Hypothesis: LGDs will alter wildlife behavior without excluding them from the landscape, however impacts will differ between species, number of LGDs present, and size of ranching operation.

Anticipated Value

Wildlife populations are facing global declines caused by habitat fragmentation and loss due to agriculture, as well as human-wildlife conflict (Laurance et al. 2007; Lieb et al. 2021; Wakoli et al. 2023). Wildlife conservation and human-wildlife conflict are divisive topics among conservationists, ranchers, and the public. Ranchers often kill animals they view as threats to their livestock. LGDs represent a solution for human-wildlife conflict and carnivore conservation through reduced retaliatory killings. However, empirical data is needed to demonstrate the broader ecological impacts of LGD presence on local wildlife populations. This research will fill the knowledge gap by providing one of the first quantitative analyses of the dynamics affecting the relationship between LGDs and their environment, specifically by assessing how LGD presence influences the behavior and occupation of mesopredators and herbivores.

Literature Review

Human-wildlife conflict is an issue faced by nearly every farmer, and incidents are becoming more frequent as growing human populations and urbanization force people and wildlife to share space (Lieb et al. 2021; Wakoli et al. 2023). When carnivores kill livestock, farmers often respond by killing wildlife as they consider lethal control methods to be practical and economical (Potgieter et al. 2015; Spencer et al. 2020). Despite its popularity among agriculturalists, retaliatory killings only offer short-term solutions, and often have cascading effects on small predator and prey species (Treves & Naughton-Treves, 2005). A growing body of evidence suggests that LGDs significantly reduce livestock loss to predators and reduce retaliatory killings of the target species they guard against (Andelt & Hopper, 2000; Potgieter et al. 2015; Rust et al. 2013), which thus supports their status as a strategy for large carnivore conservation. Studies evaluating farmers' perceptions of LGDs and wildlife show a shift from negative to positive views of carnivores and a perceived increase in numbers of target predators (Gonzalez et al. 2012; Potgieter et al. 2015). LGDs' ability to alter people's perceptions of wildlife is important for wildlife conservation, as agricultural lands provide critical habitat for wildlife, and conservation efforts often rely on voluntary participation of landowners (Gehring et al. 2010; Reiter et al. 2021). Nevertheless, there are minimal empirical data regarding the ecological impacts on nontarget wildlife species when LGDs are used (Kinka et al. 2021).

The relationship between LGDs and local wildlife needs to be more fully assessed and better understood to provide best management practices when it comes to overall wildlife conservation on agricultural land. The influence LGDs have on wildlife activity is not well understood (van Bommel & Johnson, 2016). Many conservationists raise concern regarding LGDs' ecological impacts, especially when it comes to potentially lethal interactions with wildlife (Kinka et al. 2021; Lieb et al. 2021). While usually opting for indirect cues such as scent marking and vocalization to deter predators, LGDs have been reported to chase, harass, and kill wildlife (Gavagnach & Ben-Ami, 2023; Lieb et al. 2021). Large carnivores show avoidance of LGDs, without being excluded from the landscape (Kinka et al. 2021; Spencer et al. 2020). This demonstrates that large carnivores can persist in agricultural areas (Bromen et al. 2019), however, there is no empirical evidence assessing how LGDs influence mesopredators and herbivores. LGDs may act as a surrogate top predator in the absence of large carnivores; influencing dynamics among mesopredators, however this has not been studied (van Bommel & Johnson, 2016). Additionally, LGDs may play a role in reducing disease transmission between wild ungulates and livestock as well as controlling grazing pressure, but this has not been assessed (van Bommel & Johnson, 2016). More research will provide critical information regarding the ecological impacts of LGDs on both target and nontarget wildlife species.

Methods

Survey

The first step for data collection in this project will be identifying ranchers willing to participate in the study. I will survey landowners in Routt County (Fig. 1), located in northwestern Colorado, where wolves are planned to be reintroduced and human-wildlife conflict is a topic of concern. I will include ranches with and without LGDs in this study. Survey questions will include:

What is the size, in acres, of your operation?	What is the land use of the adjacent properties?
What type of livestock do you run?	Do you use livestock guardian dogs (LGDs)?
How many head of livestock do you run?	Do you have non-guarding dogs?

If LGDs are present, the following additional questions will be asked:

How long have you used LGDs?	Age(s) of LGD?
How many LGDs do you have?	Do your LGDs stay on property 24/7?

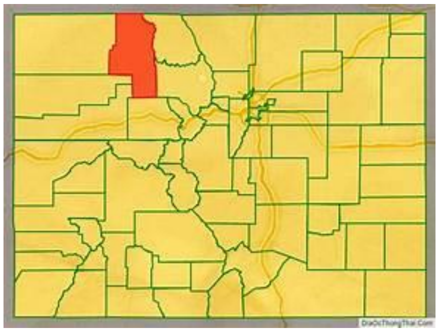

Figure 1. Map of Colorado state with county borders. Study site, Routt County, highlighted in red.

Camera traps

To obtain data regarding wildlife species' occupation in agricultural areas, I will conduct a camera trap survey. Data from the camera traps will be used to identify the wildlife species that occur in areas near ranches. I will place a total of 5 camera traps at each ranch; one on the fence line of each property that will be considered the center of the field of study, and additional camera traps will be placed 1km away in an east-west direction (in the property boundaries and outside of the property boundaries) and 5km away in an east-west direction (Fig. 2). This ideal set up may need to be altered based on specific ranches if there is no consent to place traps on neighboring properties. To account for seasonality and temporal changes, this study will take place over the course of one year. Camera traps will be located at two ranches simultaneously; one with LGDs and one without, and will be in place for 2 weeks, then moved to another two ranches and so on for the duration of the study.

After collecting camera trap photos every 2 weeks for one year, I will upload them to Zooniverse, a citizen science platform that allows the public to aid and participate in scientific research. On Zooniverse, participants will identify the species present and record the number of animals visiting during each visit as well as the duration of visit, over a 24-hour time period. For each species and 24-hour time period I will quantify the total number of observations, mean group size, and mean duration of observation.

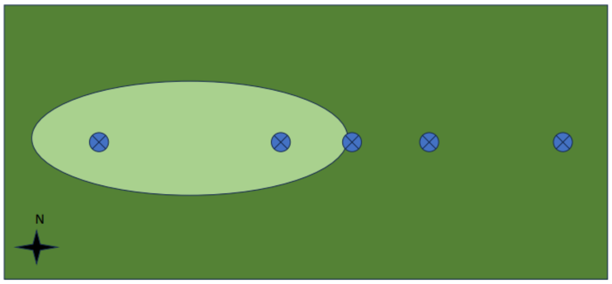

Figure 2. Study design. Blue circles represent camera trap position on fence line, 1km away in both directions, and 5km away in both directions. Light green oval represents ranch boundaries, while dark green represents adjacent property.

Data Analysis

I will analyze these data using generalized linear mixed models (GLMs) in R. The specific ranch identity will be used as the random effect, while the position of camera trap and presence/absence of LGD will be used as the main fixed effects. The response variables will be total number of observations for each species, mean group size of each species, and the mean duration of observation.

Project Schedule

Table 1. Project Schedule including dates, activities, and deliverables

Dates	Activities	Deliverables
January 2024	Identify participating ranches Survey landowners	Camera locations & schedule Survey data
February 2024-2025	Place traps every 2 weeks Community engagement	Photos
March-April 2025	Upload photos to Zooniverse Begin report	Raw data
May-June 2025	Analyze data	Draft report
September 2025	Finish report	Final report

Budget

Table 2. Budget including items, justification, cost per unit, quantity, and total cost.

Item	Justification	Cost, unit	Quantity	Total cost
Reconyx HyperFire™ PC900 with IR flash camera traps	Collect data	$400	10	$4,000
256GB SanDisk Ultra SDXC memory cards	Store data	$50	30	$1,500
Gas	24 round trips	$0.62	1,200	$744
Stipend	Compensation	$3,756	1	$3,756
Total cost				$10,000

Qualification of Researchers

Megan E. Gaeth
megaeth@gmail.com
303-550-2837

EDUCATION

Regis University, Denver, CO May 2024
Master of Science in Environmental Biology
Guilford College, Greensboro, NC May 2017
Bachelor of Arts in Biology

RESEARCH EXPERIENCE

Denver Mountain Parks Spring 2024
Human-elk conflict in Dedisse Park, Evergreen, CO
- Data analysis: R studio; GIS to map presence and conflict coordinates in ArcPro; presented results in written and poster reports

Regis University 2022-2024
Effects of one-rock dams as erosion mitigation
- Data collection: quadrat sampling; vegetation ID; data analysis: R studio; presented results in written, poster, and oral reports

Nighttime behavior of bull Asian elephants at Denver Zoo
- Data collection: Zoomonitor; continuous focal sampling; presented results in written and oral reports

WORK EXPERIENCE

Denver Mountain Parks, Morrison, CO Spring 2024
Intern
- Analyzed and presented on human-elk conflict in Evergreen, CO; installed kestrel nest boxes; constructed fencing as part of grazing exclusion experiment; attended management meetings

Rainbow Trout Ranch, Antonito, CO Seasonal 2018-Present
Wrangler
- Guided and led trail rides for guests on horseback, including wrangling, saddling, care and maintenance of roughly 150 horses; taught guests to ride, including giving orientations and equitation, led hunters and pack horses to remote camps and packed elk; operated ranch vehicles and two-way radios

Clovertop Creamery, Charlottesville, VA Seasonal 2018-2020
Farmhand
- Cared for a herd of 40 goats, including bottle feeding, vaccinations, cleaning stalls; fed and cared for donkeys, horses, chickens, and livestock guardian dog; aided in delivery of pregnant does; operated milking equipment; made and packaged cheese

RELATED SKILLS

Safety trainings: CPR and Wilderness First Aid certified
Field Procedures: transect counts, capture-mark-recapture, freshwater sampling, invasive species removal
Computers: Microsoft word, Excel, R, ArcGIS, PowerPoint, Google Docs
Language: Proficient in conversational Swahili
Writing: Scientific writing, NEPA writing, grant proposals

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Spencer, K., Sambrook, M., Bremner-Harrison, S., Cilliers, D., Yarnell, R. W., Brummer, R., & Whitehouse-Tedd, K. (2020). Livestock guarding dogs enable human-carnivore coexistence: First evidence of equivalent carnivore occupancy on guarded and unguarded farms. *Biological Conservation*, *241*, 108256.

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van Bommel, L., & Johnson, C. N. (2016). Livestock guardian dogs as surrogate top predators? How Maremma sheepdogs affect a wildlife community. *Ecology and Evolution, 6*(18), 6702-6711.

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CHAPTER 3. JOURNAL MANUSCRIPT

Assessing human-elk conflict at Dedisse Park

Abstract

Human-wildlife conflict is increasing globally as landscapes become more urban, reducing and fragmenting habitat for wildlife and bringing them closer to people. In the Western United States, elk and human populations are both growing, leading to increased rates of human-elk conflict. This study took place in Evergreen, CO, where Dedisse Park experiences high levels of human activity and elk presence. We aimed to determine where conflict is most prevalent and to determine which environmental and behavioral factors contribute to human-elk conflict. We found that conflict occurs primarily along the north side of the lake and that people and elk are likely to be present when temperatures increase and wind and precipitation are not present. Finally, we found that walking and driving a car had significant effects on elk feeding behavior. The results of this study provide management implications for Dedisse Park, and contribute to our understanding of human-elk conflict in western North America.

Introduction

Growing human populations and increased urbanization cause habitat encroachment and fragmentation, forcing people and wildlife to share space (Gilleland, 2010). As a result, rates of human-wildlife conflict are increasing globally (Lieb et al. 2021), and examples of such conflict include crop and vegetation damage, livestock and domestic animal predation, disease transmission, chasing and injury of humans, and vehicle collisions (Callon, 2023; Messmer, 2009; Patterson et al. 2003). When people recreate outdoors, human-wildlife interactions are nearly inevitable as parks and golf courses represent critical habitat for wildlife in urban areas (Tietge, 2020).

Often, wildlife represents an attraction for people, drawing them to recreate in a specific area, but observing and enjoying wildlife can turn into conflict (VerCauteren et al. 2005). Conflicts related to recreation can be costly, and include vegetation and property damage, traffic incidents, and direct interactions between people, their pets, and wildlife, which can be fatal or injurious to all parties (Distefano, 2005; Patterson et al, 2003). Research suggests that human behavior, rather than wildlife behavior, is the main contributor to human-wildlife conflicts (Kubo & Shoji, 2014). When these conflicts occur in areas designated for human use and recreation, the managers of these properties are faced with challenging decisions about how to mitigate these conflicts.

Recreation and conservation are two land management goals that are often at odds with one another, presenting managers with the predicament of maintaining the delicate balance between protecting wildlife, promoting recreation, and ensuring the safety of humans and animals (Haggerty & Travis, 2006; Messmer, 2009). Managing ecosystems in the western US is complicated by demographics, socioeconomics, and land use changes (Haggerty & Travis, 2006). Additionally, human and wildlife behavior is difficult to predict, and solutions are often circumstantial and short-term as nuisance animals can quickly become habituated and desensitized to hazing techniques (Callon, 2023). To implement management decisions that benefit humans and wildlife, it is important for land managers to know how and why conflict occurs, the scope and magnitude of the conflicts, and which species are involved (Messmer, 2009).

Rocky Mountain elk (*Cervus canadensis nelsoni*) are a species often involved in human-wildlife conflict in the Rocky Mountains of the western United States, in part due to hunting regulations and shifting public opinion of lethal management techniques (Haggerty & Travis, 2006; VerCauteren et al. 2005). Despite rapid human population growth throughout western North America causing fragmented habitats, elk populations are increasing (Cleveland, 2010). Increased human and elk populations lead to higher rates of human-wildlife interactions, which include conflicts such as reduction in aspen *(Populus tremuloides)* and willow *(Salix exigua)* populations, vehicle collisions, and injury to both humans and wildlife (Callon, 2023; Messmer, 2009). Human-elk conflict poses an issue in wildland urban interfaces (WUI), where human and elk populations have rapidly increased for the last century (Callon, 2023). When multiple stakeholders are involved in managing wildlife corridors, including public and private entities, cooperative management is a necessary challenge (Haggerty & Travis, 2006). Fragmented habitats threaten biodiversity, therefore maintaining wildlife corridors and habitat connectivity is crucial for preserving local biodiversity (Laurance et al. 2007).

Evergreen, Colorado is a WUI experiencing increased rates of human-elk conflict at Dedisse Park, which incorporates Evergreen Lake and Golf Course. The goal of this current study is to understand the environmental and behavioral factors that contribute to human-elk conflict at Dedisse Park. We collected data regarding elk presence and behavior and park usage by people, documenting specific conflicts when they occurred, in addition to simultaneously recording environmental data during behavioral observations. The results of this study will be used to inform management decisions such as hazing, fencing, and increased enforcement of wildlife regulations (i.e. leashing dogs and maintaining distance from elk) by identifying the anthropogenic and environmental drivers of human-elk conflict at Dedisse Park.

Methods

Study Area

We conducted this study at Dedisse Park, located in Evergreen, CO, which includes Evergreen Lake and Golf Course, encompassing a total of 420 acres. People use the area for many recreational activities, including walking/running, dog walking, cycling, fishing, photography, golf, and water activities. Dedisse Park is jointly managed by Denver Mountain Parks and Evergreen Parks and Recreation. The park is adjacent to open spaces owned and managed by Denver Mountain Parks and Jefferson County, as well as private lands that form a wildlife corridor. Elk using this corridor also spend time in the park feeding and resting, most frequently during calving season in the spring and rutting season in the fall (Callon, 2023).

Field Data Collection

To investigate how recreation at Dedisse Park influences elk behavior, students from Metropolitan State University collected data from May to October in 2023, spanning the spring calving season and fall rut when elk are most abundant in the surrounding area (Callon, 2023). Students used Survey 123 to record data (ESRI, Redlands, CA), recording elk presence, number of elk, elk behavior, and human activity level of the park. The activity level of the park was holistically assessed and scored as an ordinal variable with a range of 0 to 5, with 0 indicating activity level was low, and 5 indicating a high level of human activity at the park. If a human-elk interaction occurred, the researchers recorded elk response to humans, such as stopping feeding, pinning ears, charging, raising hair, and running away. If an interaction occurred, investigators also documented the activity of the people, the presence of dogs and their behavior, traffic involvement, and the person's or people's distance to elk. Finally, researchers recorded temperature, precipitation, and wind.

Statistical Analysis

To visualize conflict hotspots, we plotted elk presence and conflict coordinates in ArcPro (ESRI, Redlands, CA). In order to test how recreation at Dedisse Park affects elk behavior, we analyzed data from two datasets, one regarding elk and human presence, the other documenting human and elk behavior if an interaction occurred in R 4.3.2 (R Core Team, 2023). The presence data was analyzed using generalized linear models (GLMs), where the predictor was business of the park. We analyzed elk presence as a binary response variable with a binomial link function, and we analyzed the number of elk as a count-based response variable with a Poisson link function. We also examined whether environmental predictors that included temperature, precipitation, and wind improved the fit of these models.

The conflict data was analyzed using several logistic regressions in which we modeled each elk behavioral response as a function of each human activity. Predictor variables were distance to elk and human activity as a binary variable, and response variables were the occurrence or absence of elk behavior as a binary response. We assessed model fit using AIC values, with ΔAIC values > 4 indicating a significantly better model, and we considered p-values less than 0.05 significant.

Results

GIS Analysis

Our preliminary mapping of elk observations and conflicts revealed a notable spatial clustering of human-elk conflict within Dedisse Park (Figure 1). Elk were primarily located around the lake, gathering in the willows and islands. Conflict occurred on the northern side of the lake, where Highway 74 intersects Evergreen Parkway. The walking trail surrounds the lake, forming a bottleneck near this intersection with a guardrail near the road, and islands with willows where elk congregate to calve, nurse, and feed.

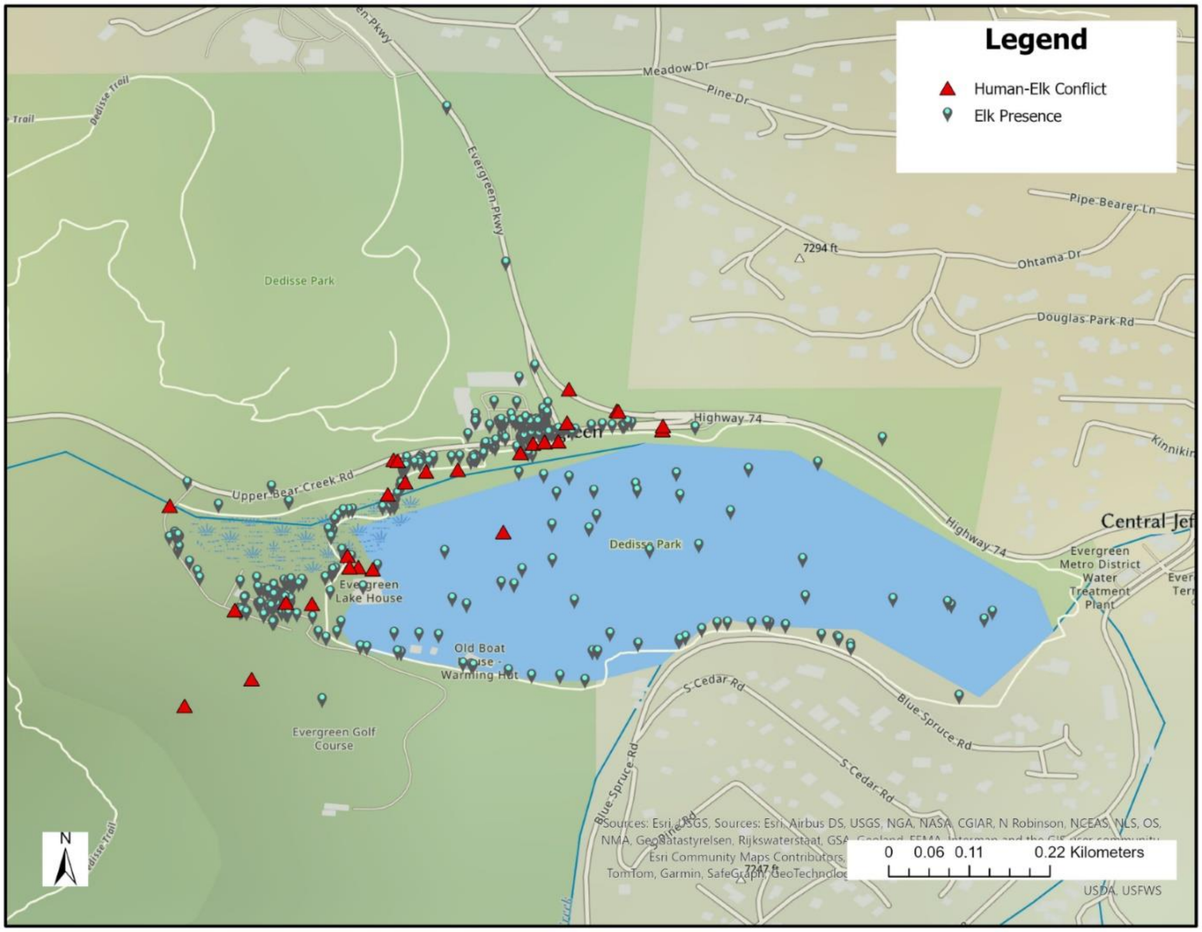

Figure 1. Elk congregate around Evergreen Lake and in the surrounding wetlands. Human-elk conflict is most prevalent on the northern side of the lake where Evergreen Parkway and Highway 74 intersect, and near the lake house.

Elk Presence and Abundance

We found a significant positive relationship between how busy the park is and the odds of elk being present. The best model included business of the park, plus wind, temperature, and precipitation as co-predictors. However, a model including only business and wind was comparably good, as determined by ΔAIC values (ΔAICc = 1.20). After accounting for the effects of wind, temperature, and precipitation, as business of the park increased by one point, the odds of elk being present increased by 70% (95% CI: 36%-113%, $p < 0.001$). When temperature increased by one degree Celsius, the odds of elk being present decreased by 14% after accounting for all other variables (95% CI: 10-17%, $p < 0.001$). During precipitation, the odds of elk being present increased by 72% when accounting for all other variables. (95% CI: 5% decrease-207% increase, $p = 0.070$). There were very few observations with wind, so the inferred effect of wind on elk presence was essentially zero (1.67×10^{-7}, $p = 0.979$).

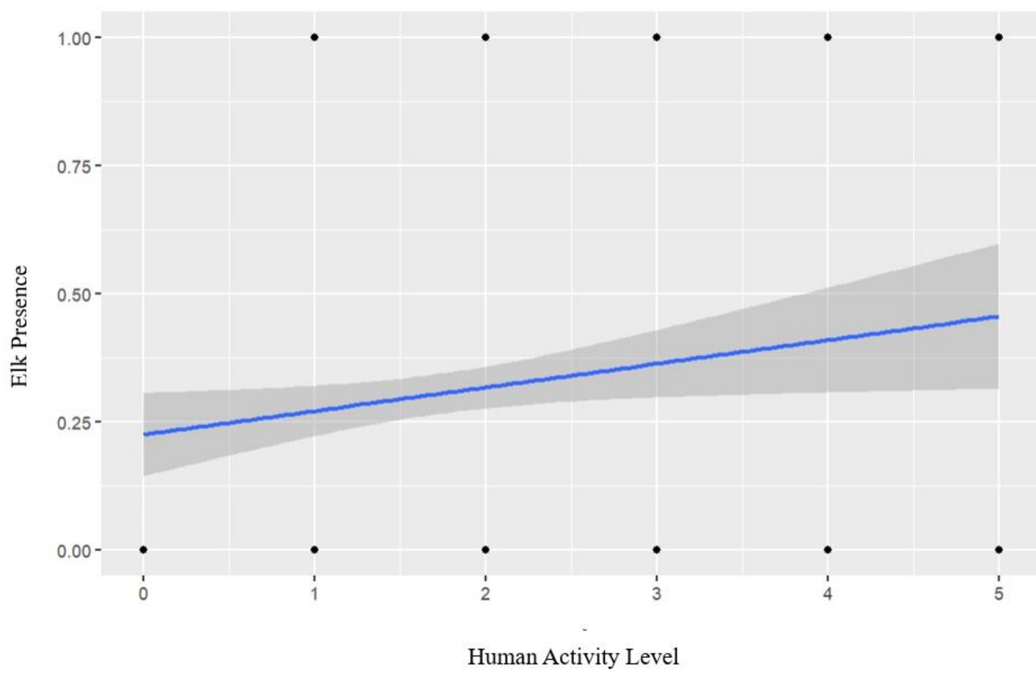

Figure 2. Elk are more likely to be present on busy days at Dedisse Park. Points represent stacked observation periods, the blue line represents the best fitting logistic regression, and the shaded gray area represents the 95% confidence interval of the regression.

We also found a significant, positive relationship between business of the park and elk abundance. The best model included business of the park, with the effects of wind, temperature, and precipitation as co-predictors. However, a model excluding precipitation was comparably good as determined by ΔAIC values (ΔAIC = 0.51). With other variables held constant, an increase in business of the park by one point was associated with a 21% increase in elk abundance (95% CI: 15-27%, $p < 0.001$). When accounting for all other variables, temperature was associated with a 15% decrease in abundance (13-15%, $p<0.001$). Precipitation was associated with a 12% decrease in abundance when accounting for all other variables (25% decrease - 3% increase, $p = 0.116$). There were very few observations with wind, so the inferred effect of wind on elk abundance was essentially zero ($1.75\text{-}10^7$, $p= 0.950$).

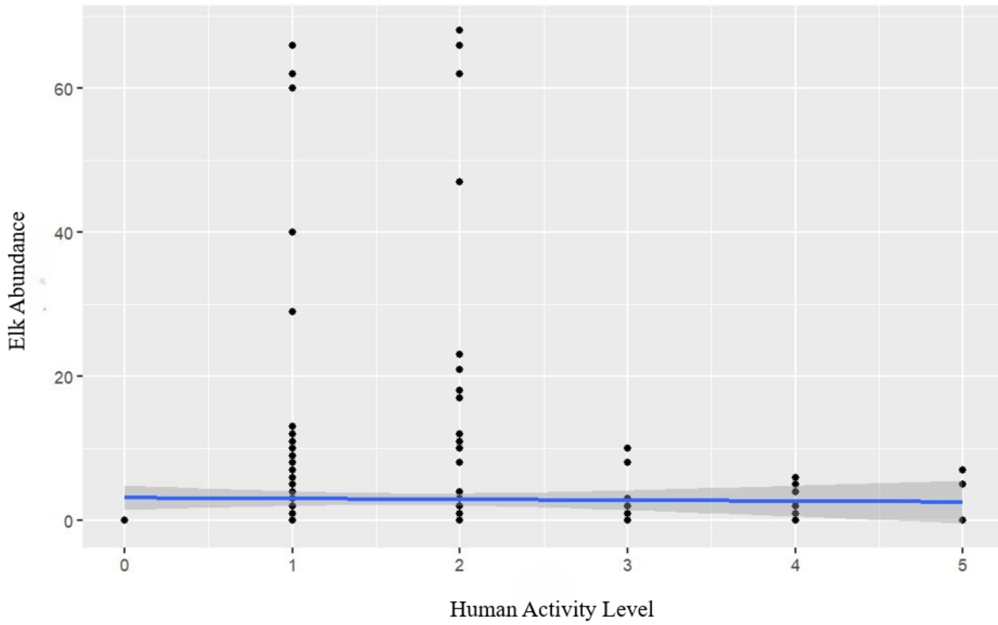

Figure 3. Elk are present in greater abundance on busier days at Dedisse Park. Points represent individual observation periods, the blue line represents the best fitting Poisson regression, and the shaded gray area represents the 95% confidence interval of the regression.

Human-Elk Conflict

We found no significant relationship between distance to elk and displayed elk response when assessing how distance to elk affects elk behavior. However, the odds of elk displaying some behaviors increased when distance to elk increased, while the odds of other elk behaviors decreased when distance to elk increased. When assessing how specific human activities influence elk behavior, we found that walking and driving a car both significantly influenced feeding behavior. When walking, the odds of an elk stopping feeding increased by 7.14-fold (95% CI: 1.36 - 56.81-fold increase, p = 0.03). When driving a car, the odds of an elk stopping feeding decreased by 9% (95% CI: 0.41-67%, p = 0.04).

Table 1. Elk behaviors in response to human activity. Each column represents one of the observed human activities, and each row represents one of the observed elk behaviors. A + or – indicates whether odds of the behavior increased or decreased, with corresponding p-value in parentheses, bolded values indicating significant responses, and italicized values indicating borderline significant responses.

ELK BEHAVIOR	DISTANCE	WALKING	BIKING	PHOTOGRAPHY	CAR	FISHING	WATCHING	WATER ACTIVITY
STOP FEEDING	+ (p=0.23)	+ **(p=0.03)**	– (p=0.79)	– (p=0.55)	– **(p=0.04)**	+ (p=0.99)	+ (p=0.79)	+ (p=0.99)
APPROACH	+ (p=0.15)	+ *(p=0.08)*	– (p=0.99)	– (p=0.24)	– (p=0.63)	+ (p=0.99)	+ (p=0.95)	+ (p=0.99)
RUN AWAY	+ (p=0.99)	– (p=0.19)	+ (p=0.99)	– (p=0.11)	+ *(p=0.06)*	+ (p=0.99)	+ (p=0.51)	+ (p=0.99)
EARS BACK	+ (p=0.38)	– (p=0.67)	+ (p=0.99)	+ (p= 0.59)	+ (p=0.12)	+ (p=0.99)	+ (p=0.10)	+ (p=0.99)
RAISE HAIR	+ (p=0.99)	+ *(p=0.078)*	+ (p=0.99)	- (p=0.24)	+ (p=0.99)	+ (p=0.99)	+ (p=0.95)	+ (p=0.99)
CHARGE	+ (p=0.99)	– (p=0.99)	+ (p=0.11)	+ (p=0.51)	+ (p=0.99)	+ (p=0.99)	+ (p=0.81)	+ (p=0.99)
ROAD	+ (p=0.44)	+ (p=0.71)	+ (p=0.17)	– (p= 0.33)	+ (p=0.99)	+ (p=0.99)	+ (p=0.29)	+ (p=0.99)

Discussion

The goal of our study was to determine how recreation at Dedisse Park affects elk behavior. We collected data from May-October 2023, recording elk and human presence, as well as elk behavior and human activity when an interaction occurred. When mapping these data, we found that conflict is common along the northern edge of Evergreen Lake, with the potential to impact foot and vehicle traffic. People and elk are most likely to be present and in higher numbers when the weather is warmer. Finally, we found that foot and vehicle traffic have the biggest impact on elk behavior, although there were relatively few effects of human recreation behavior on elk behavior. These results provide insights into location and factors that contribute to human-elk conflict that will inform management decisions at Dedisse Park. Additionally, these results contribute to a growing body of literature assessing the drivers of human-elk conflict in western North America.

GIS Analysis

After analyzing elk presence and conflict spatial patterns, we found that elk are common throughout the whole park but most conflict happens along the northern side of the lake where the trail narrows to a bottleneck along Highway 74. The northern edge of the lake is dominated by willows where the elk congregate to calve, nurse, and feed. This area is a hotspot for conflict, as the nature of the walking trail puts people near the elk, with nowhere to go but the road if conflict occurs. Another area with increased conflict is near the lake house, which could be attributed to the high levels of people in the parking lot and near the building, as well as another wetland habitat that may attract the elk. These results are consistent with findings from Ager et al. (2003) in which elk shift down-slope and near water later in the day (Ager et al. 2003). Understanding the factors that contribute to conflict is important in managing humans and wildlife and avoiding risks, such as human-wildlife conflict (Olson et al. 2019). The map we generated in this study provides a visual aid for land managers to understand which areas of Dedisse Park are hotspots for human-elk conflict. This visual understanding will aid in management decisions aimed at reducing human-elk conflict. More data regarding elk movement at Dedisse Park will inform managers about the location and timing of conflict.

Elk Presence and Abundance

Business level of the park, including the effects of climatic co-predictors, is a strong predictor for both elk presence and abundance. In our analysis, the best model included all the climatic variables. This suggests that people and elk flock to the park when the weather is calm, not raining, and warm. However, higher numbers of people and elk increases the potential for conflict. Our results are consistent with other studies that correlated higher temperatures with increased human-wildlife conflict (Nayeri et al. 2022; Newsom et al. 2023).

Human-elk Conflict

We found that walking and driving a car were the only human activities that significantly affected elk behavior. Our lack of significant results when looking at the influence of different human activities on different elk responses is possibly because we only have data from one season of sampling. However, the lack of these effects may also be attributed to the multiple variables that influence human activity on local wildlife, including the type of human activity, wildlife species involved, options to flee or hide, and presence of young (Tablado & Jenni, 2017). We found that walking had a strong, negative correlation with feeding, meaning as a walker decreased in distance to elk, the elk were likely to stop eating. Walking also had strong, borderline significant effects on whether elk approached people or raised their hair. This finding suggests that as a walker decreased their distance to elk, the individual animal was likely to stop eating, approach the person, and raise its hair. This response may be an attempt by elk to make themselves appear bigger and more intimidating; a tactic to discourage the person from getting any closer (Hirth & McCullough, 1977). While walking decreased feeding behaviors, driving was found to increase feeding behaviors, suggesting that elk may be habituated to vehicles, but that they are vigilant around people. The results from our conflict data analysis somewhat contradict those of other studies that found high elk avoidance of recreation trails and concluded that elk are sensitive to human presence (Wisdom et al. 2018). However, the motivation and habituation of local populations or individuals may influence human and trail avoidance (Jones et al. 2021; VerCauteren et al. 2007). Long-term monitoring of human-elk interactions at Dedisse Park will provide more insights into how specific human activities influence certain elk behaviors. Additionally, present data collection methods limited the scope of our results as we only recorded human activity and elk response when a conflict occurred. Future data collection should record human activity and elk behavior in the absence of a conflict, as negative controls will improve the statistical power of our results.

Management recommendations

To best ensure the safety of people and elk at Dedisse Park, an adaptive management strategy is crucial. Adaptive management is the practice of monitoring and evaluating management decisions in order to learn from and improve on them in the future, and this practice is crucial for promoting coexistence and reducing human-elk conflict at Dedisse Park (Denryter & Heeren, 2021). Lethal and non-lethal techniques have varying success rates over time (Jones et al. 2021; Walter et al. 2010), therefore, leveraging multiple strategies will increase the efficacy of human-elk management at Dedisse Park.

I suggest the following management recommendations for Denver Mountain Parks to explore. First, it is in the best interest for Denver Mountain Parks to continue the long-term monitoring of the elk herd at Dedisse Park. Ongoing monitoring of human-elk interactions at Dedisse Park will improve the effectiveness of management strategies, as understanding the timing, duration, and public perception of these techniques increases the potential for successful management techniques (Walter et al. 2010). Knowing which factors increase the likelihood of conflict occurring is essential for reducing human-wildlife conflict (Olson et al. 2019). The second management strategy is increased patrol of rangers to enforce rules regarding distance to elk, leashing dogs, and diverting routes when elk are present. Denver Mountain Parks should consider hiring full-time staff employees combined with volunteers to patrol and enforce policies during calving and rut in order to reduce conflict (VerCauteren, 2010). The combined use of range riders, humans patrolling an area on horseback, with herding dogs is an effective way to keep elk out of conflict areas (Walter et al. 2010). These staff would be responsible for speaking with people about safety, as well as hazing elk when needed to keep them out of areas for shorter periods of time (Jones et al. 2012). Third, I recommend the use of trail closures and fencing during calving and rutting seasons because fencing has proven effective at keeping animals out of sensitive areas (VerCauteren, 2010). At Dedisse Park, managers will need to use fencing in order to prevent people from entering conflict zones and to control elk movement in and out of the area. This can be difficult, as VerCauteren et al. (2007) found that an animal's motivation, in this case people, determines how substantial a fence needs to be to keep them out. Denver Mountain Parks has employed temporary fencing in the past that proved to be ineffective in deterring people from entering conflict zones (S. Bartell, personal communication, 2024). Combining trail closures with increased enforcement may be the best method to keep people away from elk during calving and rut. The final management strategy to consider is habitat modification, as it can reduce human-wildlife conflict (Schell et al. 2021). Dredging the islands and constructing new wetland habitat could reroute the elk from the north side of the lake and reduce conflict. However, this would be a costly project, and modified wetlands do not always provide the same ecosystem services (Turner et al. 2001). Additionally, modified habitat may attract more elk individuals to Dedisse park, increasing the risk of human-elk conflict (Fischer & Lindenmayer, 2007).

Conclusion

Managing human-elk conflict is becoming increasingly more challenging for land managers as both elk populations and outdoor recreation are increasing, and elk are easily able to adapt to landscapes that have been altered by people (Jones et al. 2021; Tablado & Jenni, 2017; VerCauteren et al. 2005). It is important to understand how effective various management techniques are in different situations to most effectively reduce human-wildlife conflict (Jones et al. 2021). Interestingly, our findings conflict with previous work that found that elk were sensitive to human presence and showed strong avoidance of recreation trails (Wisdom et al. 2018). However, elk preference of habitat in conflict zones and habituation to people may lead them to show weaker avoidance of humans (Jones et al. 2021). When people and elk prefer the same habitat, it results in direct competition and increased risk of human-elk conflict (Olson et al. 2019), which is a consistent trend observed with increasing human-wildlife interactions across North America. Thus, consistent monitoring and informed management strategies are critical for mitigating risk and maximizing wellbeing for both people and wildlife in these changing areas.

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CHAPTER 4.

Prairie Dog Management in Agricultural Lands: A Case Study

Introduction

Prairie dogs (*Cynomys spp.)* are considered pests on agricultural land as they reduce forage, have the potential to transmit disease, and their holes can threaten livestock (Witmer et al. 2023). By the 1960s their population experienced a 98% decline (Reading et al. 2002). Typically, prairie dogs and other rodents are not viewed as charismatic, or of conservation concern, by the general public (Elmore et al. 2007). However, the discovery of a population of the previously thought-to-be-extinct black-footed ferrets (*Mustela nigripes*) in the mid 1900s increased consideration of prairie dog conservation because prairie dogs constitute 60-75% of the black-footed ferrets' diet (Brickner et al. 2014). Some scientists claimed that prairie dog's role as the primary food source for black-footed ferrets makes them a keystone species, while others questioned what additional services prairie dogs contribute to the ecosystem (Kotliar et al. 1999; Reading et al. 2002). Regardless of whether they are a keystone species, the ecosystem services that prairie dogs offer, such as grassland modification and providing a food source and habitat for endangered species, including black-footed ferrets and burrowing owls (*Athene cunicularia*), cannot be ignored (Witmer et al. 2023).

This debate regarding their status as a keystone species, coupled with prairie dogs being perceived as nuisance animals, creates challenges for land managers. Direct management solutions need to be provided, because it is difficult to alter people’s perceptions of wildlife. Residents of Colorado who experience direct impacts from prairie dogs are more likely to have negative views of prairie dogs compared to residents who aren’t directly affected by these animals (Zinn & Andelt 1999). Additionally, these residents in agricultural communities tend to have more ecosystem level knowledge regarding the species, so educating local stakeholders is unlikely to change their negative opinions (Elmore et al. 2007).

On agricultural lands, many ranchers view prairie dogs as pests that drastically reduces forage for livestock (Reading et al. 2002); thus, many ranchers often attempt to exterminate prairie dog colonies (Kotliar et al. 1999). Policy and management of prairie dogs in Colorado has a history of controversy between ranchers and environmentalists (Reading et al. 2002). This paper explores the conflict surrounding a Gunnison's prairie dog (*Cynomys gunnisoni*) colony located in the San Luis Valley of Southern Colorado. This colony is in the Conejos River Valley in Antonito, Colorado and extends across a private property, a dude ranch, and a national forest. Much of the prairie dog colony is located on the private property, with the edges of the colony expanding under the barbed wire fence into the ranch's property to the east, and national forest to the west. I recommend a combination of fencing to exclude prairie dogs from certain areas of the pasture combined with the introduction of black-footed ferrets to control the population.

Stakeholders

Private Landowners

Rainbow Trout Ranch is a dude ranch that operates from May-September and takes guests on horseback rides in Rio Grande National Forest. Roughly half of all rides travel through the prairie dog colony to access the forest. The ranch has mixed feelings regarding prairie dogs (J. Ven Berkum, personal communication, March 16, 2024). The operators of Rainbow Trout Ranch recognize the ecological importance of a balanced ecosystem and the biological importance of prairie dogs to this landscape (J. Ven Berkum, personal communication, 2024). However, they feel negatively towards them as their holes pose a potential serious threat to horses and guests (J. Ven Berkum, personal communication, 2024). Horses can step in a hole, potentially injuring themselves and/or guests. In addition to threatening injury, the prairie dogs compete for forage with the horses when the herd is turned out to graze in the pasture where the colony is located. The ranch also views the holes as detracting from the aesthetics of the landscape (J. Ven Berkum, personal communication, March 16, 2024). To manage the prairie dog colony, the ranch has employed lethal methods such as shooting and poisoning prairie dogs, neither of which has visibly impacted the prairie dog population (J. Ven Berkum, personal communication, 2024). The ideal management plan for Rainbow Trout Ranch includes partial or full relocation of the colony (J. Ven Berkum, personal communication, 2024).

In addition to affecting the operations of Rainbow Trout Ranch, this colony impacts the Thompson family, whose private vacation home encompasses most of the prairie dog colony and is adjacent to both Rainbow Trout Ranch and Rio Grande National Forest. The Thompsons view prairie dogs negatively. They consider prairie dogs a nuisance that detracts from the aesthetics of the landscape, damaging vegetation and property (J. Ven Berkum, personal communication, 2024). The Thompson's have not employed any management techniques for this colony, allowing the ranch to take charge of managing the colony (J. Ven Berkum, personal communication, 2024).

US National Forest Service

The prairie dog colony extends into the Rio Grande National Forest. The US national forest service has the unique challenge of balancing the needs of ranchers, recreationists, and wildlife. The forest service views prairie dogs as a native species in its historical range and an integral part of the ecosystem (W. Remshardt, personal communication, 2024). In the Rio Grande National Forest, Gunnison's prairie dogs are of conservation concern (W. Remshardt, personal communication, March 27, 2024). Land management seeks to reduce habitat loss and ensure colonies are not infected with the plague (Dallas & Perez, 2020). The forest service recognizes the pivotal role prairie dogs play in the conservation of the critically endangered black-footed ferret. The USFS does not have any empirical evidence of a population of black-footed ferrets in the Conejos River Valley, but there are anecdotal reports of these individuals' sightings. In addition to their importance as a food source for black-footed ferrets, prairie dog holes provide habitat for other species (Witmer et al. 2023). The forest service has not employed any management measures on this particular colony (W. Remshardt, personal communication, 2024).

Environmentalists

Environmentalists are against the removal and lethal management techniques of prairie dogs, and they typically advocate for increased land management (Reading et al. 2002). These groups include Defenders of Wildlife, The Nature Conservancy, Prairie Dog Coalition, and Prairie Protection Colorado. The latter two groups are committed specifically to preserving prairie ecosystems and prairie dogs due to their inherent right to exist and their pivotal roles in the ecosystem as a whole. The Prairie Dog Coalition works to conserve prairie dogs, noting their importance to the landscape as keystone species and ecosystem engineers (Prairie Dog Coalition, n.d.). They work to stop corporations, businesses, and government agencies from lethally removing prairie dogs (PPC, n.d.). These groups would oppose the removal, lethal or non-lethal, of this prairie dog colony.

Recommendation

I propose a two-part management recommendation for this colony of prairie dogs that involves Rainbow Trout Ranch and the forest service. The first part involves the ranch and includes building fencing structures to contain the colony and exclude the prairie dogs from certain areas of the Thompsons' pasture. To be most effective, the fencing should surround the colony, therefore the landowners and forest service will need to agree to allow this fencing to be constructed on all three properties. Provided they are sturdy enough to withstand wind and breaching, barriers can be used to cease the expansion of established colonies and decrease human-wildlife conflict (Witmer et al. 2008). I recommend starting with a GIS analysis to determine current colony boundaries and where to fence to contain the prairie dogs. I recommend either fiberglass or metal as the fencing material, with taller vegetation used as a visual barrier because these techniques are effective in reducing breaching of the barrier by prairie dogs (Witmer et al. 2008). The fencing should be 1-2m deep and extend at least 76 cm aboveground (Witmer et al. 2008).

The second part of the recommendation is the reintroduction of black-footed ferrets to the Rio Grande National Forest. This part of the management plan involves the forest service with the reintroduction of a federally listed endangered species (USDA, 2020). This part of the management recommendation will include a population viability analysis (PVA) to determine how many breeding pairs to release to increase the probability of a population being established. This area is a candidate for the introduction of the black-footed ferret as the presence of prairie dogs is the most influential factor in habitat selection for black-footed ferrets, and the San Luis Valley is part of the ferrets' historical range (Forrest et al. 1988; USDA, 2020). The presence of more natural predators will keep the prairie dog population from increasing.

The goal of these two techniques is to prevent the colony from expanding through fencing and control the population's growth through predation by black-footed ferrets. This recommendation will satisfy most values of each of the stakeholders. Rainbow Trout Ranch and the Thompsons will see a reduction in prairie dog numbers due to predation, and the fencing will serve as protection from potential injury to guests and horses. The forest service and environmental activists will be happy with this recommendation as it protects an endangered species and allows for the conservation of prairie ecosystems. Environmentalists will be pleased with non-lethal management of prairie dogs, and an additional population of the critically endangered black-footed ferrets. This plan represents a step towards collaborative management between opposing stakeholders and a solution to a common human-wildlife conflict experienced by many landowners in the American West.

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