2025

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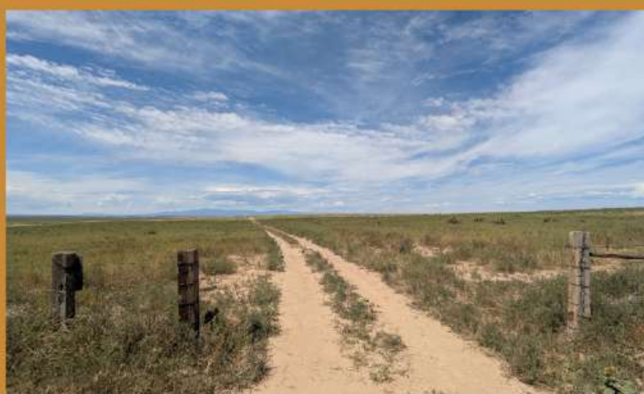
EXPLORING THE ROLE OF RAPTORS FOR ECOSYSTEM SERVICE PROVISIONING IN SOUTHERN COLORADO RANGELANDS



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Palmer LAND CONSERVANCY

AIKEN AUDUBON

Wild Birds Unlimited Nature Shop

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1 PRAIRIE DOG ECOLOGY

BLACK-TAILED PRAIRIE DOG LIFE HISTORY & LANDSCAPE IMPACTS

Kate Bicks, Stella Meister, David Zheng

Black-tailed prairie dogs are a ubiquitous sight on the shortgrass prairies of the Western Great Plains. In these regions, black-tailed prairie dogs (*Cynomys ludovicianus*) serve as important ecosystem engineers — species that actively modify their environments — to cycle soil nutrients and maintain grassland biodiversity (Hoogland, 1995). These animals have a long history of conflict with agricultural landowners who may experience detrimental effects to their livelihoods due to prairie dog activity. These concerns have merit but are important to balance with the numerous ecosystem benefits provided by prairie dogs. Herein, we synthesize how the black-tailed prairie dog, a keystone species, interacts with its surroundings in Eastern Colorado, and describe the implications this has for cattle ranching and other agricultural practices. To do so, we conducted a literature review for peer-reviewed scientific articles referencing black-tailed prairie dogs, specifically targeting studies conducted in the Western Great Plains and Eastern Colorado to highlight our area of interest. We used databases including EBSCO, Web of Science, and Google Scholar to identify relevant sources. We also referenced official U.S. government agency releases to support our research. By addressing this issue without bias, considering both ecological health and the practical needs of landowners, we aim to inform sustainable prairie dog management strategies.

Prairie Dog Life History

The black-tailed prairie dog (*Cynomys ludovicianus*) is a highly social, burrowing rodent endemic to North American grasslands. They live in complex colonies, or "towns," characterized by extensive underground burrow systems that provide shelter, facilitate predator avoidance, and serve as nesting sites (Hoogland, 1995). These rodents exhibit a single annual breeding season in late winter, yielding one litter of two to eight pups after a gestation period of approximately one month. Juvenile prairie dogs emerge from burrows in late spring, often triggering the dispersal of subadults to form new colony segments (Hoogland, 1995). Population dynamics are strongly influenced by sylvatic plague, which can cause rapid colony collapse, especially where colonies are closely spaced. This in turn affects predator populations, including ferruginous hawks and golden eagles, which rely on prairie dogs as a primary prey source (Augustine *et al.,* 2008a). Although capable of living up to eight years in captivity, wild prairie dog individuals typically survive three to four years due to predation, disease, and environmental pressures.

Prairie Dogs as Ecosystem Engineers

Prairie dogs are a keystone species and ecosystem engineers (Figure 1.1). Their presence on agricultural land increases forage quality and plant diversity for livestock and they create landscape benefits through fire mitigation, soil nutrient cycling, and habitat creation for other species. Prairie dogs also provide natural mitigation to grassland fires through their clipping behavior by reducing fuel loads and accordingly, reducing fire length and severity (Duchardt *et al*., 2025). Prairie dogs' burrowing behaviors increase bare ground, which in turn, decrease the fire's ability to spread. Frequency and intensity of fires within Colorado have increased in the past decades (Thomas Gifford & Edwared Barbier, 2025), and the ecological services provided by prairie dogs could be vital in wildfire management and building ecological resilience (Duchardt *et al.,* 2025 & Thomas Gifford & Edward Barbier, 2025).

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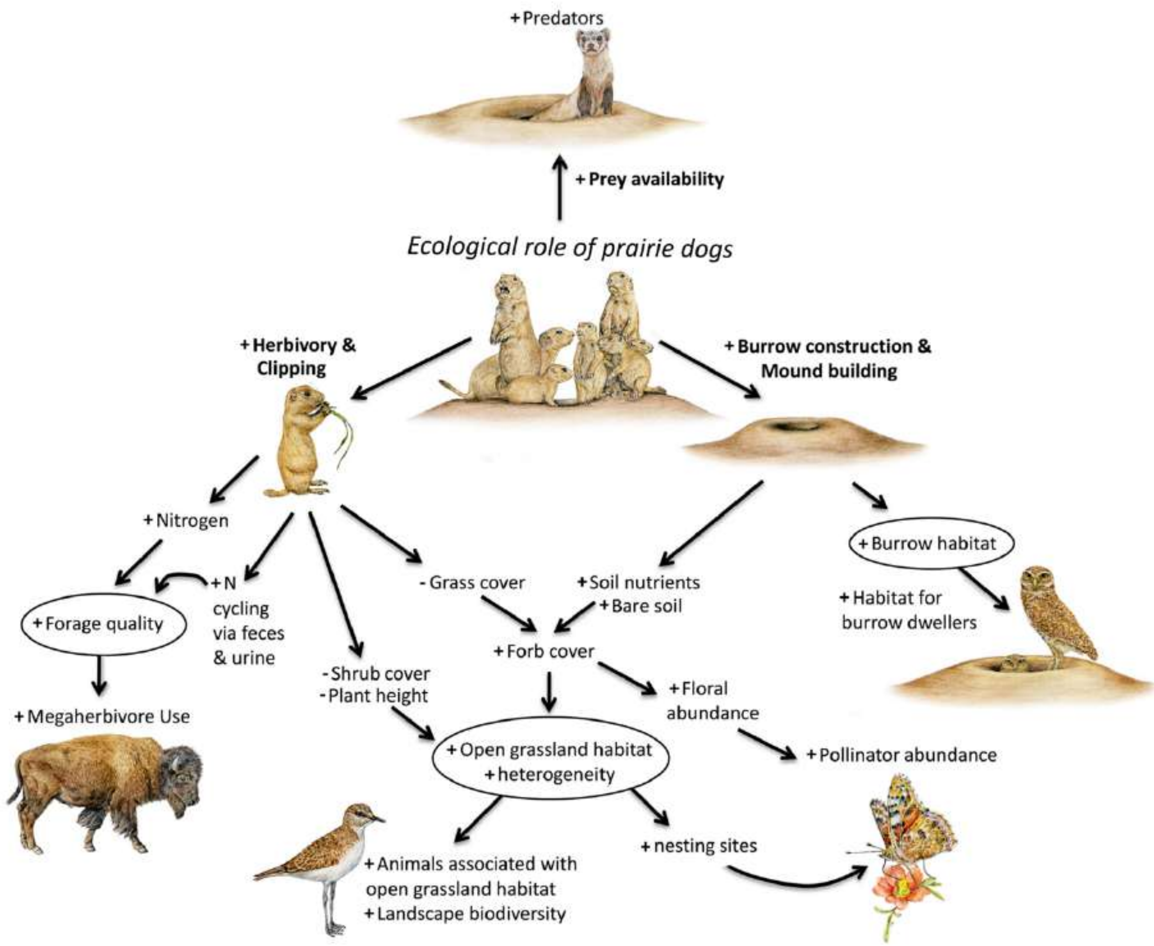

Figure 1.1. Conceptual diagram illustrating the ecological role of black-tailed prairie dogs. Plus (+) signs indicate an increase in the ecological component or process whereas minus (-) signs indicate a decrease. [Diagram created by Ana Davidson, adapted from Davidson *et al.* 2012]

Landscape Impacts

Landscape impacts on prairie dogs

Landscape structure strongly influences the distribution, persistence, and extinction dynamics of black-tailed prairie dog colonies across the Great Plains. Habitat fragmentation and land-use conversion have markedly reduced colony size, connectivity, and the availability of suitable habitat, increasing extinction risk across much of their range. Colonies located within grassland patches larger than 200 ha exhibit extinction probabilities below 10%, whereas those in smaller patches (< 50 ha) exceed 40% over a five-year period (Johnson & Collinge, 2004). Mean colony area varies widely, ranging from approximately 5 ha in fragmented landscapes to more than 140 ha in continuous native prairie (Johnson & Collinge, 2004). These differences underscore the importance of large, contiguous grassland patches for maintaining viable prairie dog populations.

Connectivity among colonies is a critical determinant of metapopulation stability. Prairie dogs typically disperse 2–6 km, with rare long-distance movements reaching up to 10-km (Wagner *et al.,* 2006). When inter-colony distances exceed 5-km, recolonization probability declines by roughly 70%, greatly limiting recovery following plague-induced collapses or local extirpations (Johnson & Collinge, 2004). Maintaining inter-colony spacing within this threshold promotes recolonization and enhances resilience across fragmented landscapes.

Topography and vegetation can constrain habitat suitability by influencing predator detection and burrow construction. Prairie dogs preferentially inhabit level terrain with slopes under 5°, avoiding areas with poor drainage or excessive vegetation height. Colonies are most successful where average vegetation height remains below 30-cm, providing unobstructed visibility and reducing predation risk (Reading & Matchett, 1997; Hoogland, 1995). Similarly, shrub encroachment and woody plant expansion suppress colony establishment; regions where shrub cover exceeds 25% contain 50–60% fewer colonies compared to open grasslands, primarily due to fire suppression and reduced grass dominance (Martínez-Estévez *et al.,* 2013).

Human land use also affects prairie dog population dynamics and impacts where prairie dog colonies occur. Moderate cattle grazing helps maintain low vegetation height favorable for colony occupation, while heavy grazing can degrade soil structure, reduce forage quality, and limit suitable burrowing areas. Conversion of native prairie to cropland or urban land fragments habitat networks, isolating colonies and restricting dispersal pathways for the prairie dogs. Colonies surrounded by cropland experience approximately 40% higher annual extinction rates than those embedded within rangeland matrices (Wagner *et al.,* 2006). Additionally, plague outbreaks in isolated colonies intensify population declines and hinder recolonization due to limited connectivity with neighboring sites (Augustine *et al.*, 2008b).

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Impact of prairie dogs on the landscape

Prairie dogs modify vegetation through intense grazing and clipping, thereby maintaining short, open grassland habitats. Black tailed prairie dogs have been documented to consume 60 to 80% of above ground annual net primary production within their colonies (Whicker and Detling, 1988). Their constant grazing and soil disturbance result in lower canopy height (Figure 1.2.), reduced litter accumulation, and decreased above- and below-ground biomass, while increasing the ratio of live to dead plant material (Coppock *et al.,* 1983; Archer *et al.,* 1987; Weltzin *et al.*, 1997).

In addition to consumption, prairie dogs actively clip vegetation to maintain sightlines across the prairie and to the sky to allow for predator scanning (Hoogland, 1995). These vegetation changes influence the relative abundance of different plant functional groups. Forb cover and biomass increase on colonies, while grass (graminoid) cover declines (Coppock *et al.*, 1983; Archer *et al.,* 1987; Fahnestock & Detling, 2002). The shift in species composition is often accompanied by higher plant species richness, especially on older colonies (Bonham & Lerwick, 1976). In a study comparing prairie dog towns of different ages, peak live plant biomass was highest on uncolonized prairie (190 g/m^2) and lowest on areas colonized for 3-8 years (95 g/m^2), but older colonies (>26 years) showed biomass (170 g/m^2) with major differences in composition. Forbs and dwarf shrubs made up over 95% of the biomass compared to >85% graminoids on uncolonized sites (Coppock *et al.*, 1983). Over time, these effects produce a heterogeneous mosaic of vegetation structure across the landscape. Vegetation responses also differ among prairie dog species and grassland types. A study spanning seven Blacktail prairie dog complexes in Northern mixed Prairie found that vegetation volume, grass cover, and tall shrub cover were lower, while bare ground and forb cover were higher on colonies compared to nearby off-colony sites (Davidson et al., 2012).

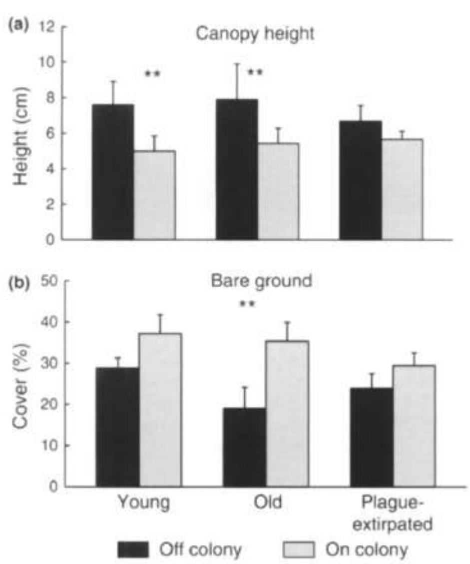

Figure 1.2. Mean canopy height (cm) and cover of bare ground (%) off and on prairie dog colonies on the Pawnee National Grassland, Colorado, USA, averaged across June and August of 2002 and 2002. Results are presented by colony type (young, old, and plague-extirpated). [From Hartley, Detling, & Savage 2009]

While studies of prairie dog complexes in Northern Mixed Prairie ecosystems found reduced vegetation volume on colonies, effects varied across ecosystems. For example, white-tailed prairie dogs in sagebrush steppe did not reduce shrub cover, while Gunnison's prairie dogs in Colorado Plateau grasslands caused relatively minor reductions in grass cover (Davidson *et al.,* 2012). These differences appear linked to the grazing tolerance of the dominant grass species and regional precipitation levels. Prairie dogs also mitigate mesquite invasion, a phenomenon indicative of desertification. In areas where mesquite shrubs are present, prairie dog grazing and digging activities reduce mesquite abundance, cover, and height more effectively than cattle grazing alone. Combining prairie dog grazing with cattle grazing showed two to five times less mesquite canopy cover compared to areas where neither was present. Mesquite encroachment reduces the quantity and quality of perennial grasses available for grazing, and dense mesquite stands form impenetrable thickets that can make grazing areas unusable, increase erosion, and hinder livestock movement and management. Over time mesquite invasion is also linked to accelerated soil erosion (Parker, 1952).

Prairie dog colonies create open habitats for numerous wildlife species. For example, prairie dogs contribute to habitat creation for rattlesnakes (*Crotalus spp.*), tiger salamanders (*Ambystoma tigrinum*), and burrowing owls (*Athene cunicularia*) (Duchardt *et al*., 2025). The prairie dog's clipping behavior also alters vegetation structure, creating open grasslands that benefit several bird species that prefer short, sparse vegetation for nesting and foraging, such as mountain plovers (*Charadrius montanus*), horned larks (*Eremophila alpestris*), and McCown's longspurs (*Rhynchophanes mccownii*) (Augustine & Baker, 2013). Despite reduced vegetative mass, prairie dog colonies supported a greater biomass of small mammals, while arthropod (mainly locust) biomass on prairie dog colonies was a third of what it was on uncolonized prairie (O'Meilia *et al*., 1982). These findings indicate that prairie dogs redistribute resources across trophic levels rather than uniformly decreasing productivity. Finally, as a keystone species, prairie dogs are also a primary prey source for predators like badgers (*Taxidea taxus*), kit foxes (*Vulpes macrotis*), swift foxes (*Vulpes velox*), bobcats (*Lynx rufus*), coyotes (*Canis latrans*), and the endangered black-footed ferret (*Mustela nigripes*).

Prairie dogs also modify the abiotic characteristics of grassland soils. Their burrowing activity brings subsoil material to the surface, aerates the soil, and increases water infiltration below ground. When prairie dogs create burrows, they are mixing through spill layers, redistributing nutrients, and increasing soil heterogeneity (Barth *et al*., 2014). Prairie dog colonies act as nutrient hotspots because they have high levels of nitrogen, phosphorus, and carbon (Barth *et al.,* 2014). This nutrient hot spot is due to prairie dogs' waste production, collection of decaying plant material for nesting, and carcass decomposition. This burrowing activity contributes to long-term www.nps.govsoil fertility, organic matter cycling, and spatial heterogeneity, which in turn helps vegetation and water retention within prairies (Barth *et al*., 2014).

Burrow mounds expose bare soil that is vulnerable to erosion, but this is mitigated to some extent by prairie dogs' habit of clipping vegetation around burrow entrances while leaving taller vegetation beyond, creating a natural windbreak that reduces wind erosion (Koford, 1958). Prairie dogs can also limit their influence on downslope soil movement through their tendency to select low-slope areas for burrowing (Koford, 1958; Reading & Matchett, 1997; Wagner & Drickamer, 2004). Nevertheless, evidence for their effect on water filtration is mixed. In one Alberta study, gopher (another small burrowing mammal) tunneling did not significantly increase soil water infiltration (Zaitlin *et al*., 2007), whereas in a Colorado shortgrass prairie, infiltration rates were higher in mound soils than in undisturbed soils (Grant *et al*., 1980). However, once soils reached saturation, volumetric soil water content did not differ between mounds and surrounding areas, and water was lost at similar rates (Grant *et al*., 1980). Other research indicates that water infiltration rates can be highest in prairie dog grasslands, averaging 357 ± 288 mm/hour, compared to 283 ± 194 mm/hour in general grasslands and 97±78 mm/hour in mesquite dominated areas (Davidson *et al*., 2010). These findings suggest that the open soil structure and reduced shrub cover within prairie dog colonies can promote localized increases in infiltration capacity, although this does not necessarily translate to higher soil moisture retention.

Prairie Dog - Cattle Interactions in Shortgrass Prairies

As two of the most prevalent herbivores living in the North American Great Plains, domestic cattle and wild prairie dogs have a storied history with one another. Over half of their annual diets overlap, resulting in both direct and indirect interactions with one another (Hansen & Gold, 1977). Throughout the 19th and 20th centuries, ranchers on western shortgrass prairies viewed black-tailed prairie dogs as grassland destroyers and competitors against cattle for limited forage resources (Knowles *et al*., 2002). This perception led state and federal agencies to label prairie dogs as a pest species in the early 20th century and began government-sponsored eradication campaigns against the rodents (Knowles *et al.,* 2002). As demonstrated above, prairie dogs are an important keystone species to maintain diverse vegetation, provide habitat for animals, and support soil health in ranched areas. Their ability to perform these ecosystem services is greatly hindered when populations are fragmented and reduced through widespread lethal control such as poisoning.

Impacts modified by external factors (climate, vegetation, population dynamics)

The relationship between prairie dogs and cattle ranching is complex, and concerns are driven by numerous factors extending beyond competition alone. Issues arise when trying to universally quantify prairie dog-cattle interactions because of the influence of external factors like climate, forage characteristics, and prairie dog population dynamics. The direction and magnitude of prairie dog impacts on cattle growth are controlled primarily by annual precipitation patterns, as wet years provide enough new sprouts and vegetation growth to support a wide variety of herbivores (Crow *et al.*, 2022; Derner *at al.*, 2006; Augustine & Derner 2021). Prairie dogs have a significant impact on vegetation diversity and richness in an area, but baseline forage availability, quality, and digestibility also play a role in how prairie dogs and cattle interact with each other by dictating how many resources each species requires in a year (Augustine & Springer, 2013). Finally, prairie dog populations are rarely stable given the plague induced boom-bust cycles they experience, leading to significant inter-annual variability in resource needs (Crow *et al.*, 2022).

One method of analyzing the impacts of prairie dogs on cattle is by studying how cattle graze in and around prairie dog colonies to understand if the rodents create unusable areas. Some researchers hypothesize that prairie dogs can improve the overall quality of vegetation by increasing species richness and keeping grasses at a younger stage of growth, thereby increasing available nutrients (Sierra-Corona *et al.*, 2015). This result has been proven in the desert grasslands of the southern U.S. and Mexico, where cattle preferentially forage around prairie dog colonies (*i.e.* spend proportionally more time grazing there than in other areas; Sierra-Corona *et al.,* 2015). However, research in the shortgrass prairies of the Great Plains has not replicated this effect and instead has found that cattle in this region did not show significant preference nor avoidance of prairie dog colonies for their grazing (Augustine & Derner, 2021; Guenther & Detling, 2003). These studies also found that when cattle were on prairie dog colonies, they continued grazing in the same location and did not move to a "better" patch of vegetation (Guenther & Detling, 2003). Overall, these behavioral studies suggest that cattle in Eastern Colorado are not being restricted in their forage range by prairie dogs, although they also may not be receiving the potential benefits of vegetation management.

Beyond individual cattle behavior, prairie dogs have been shown to have a slight negative effect on cattle growth rates and overall ranching profits, but the significance of this impact depends on many of the compounding factors mentioned earlier. Augustine & Derner (2021) proved through a 12-year study of daily cattle mass gain that under most circumstances, when prairie dog populations were managed, cattle did not necessarily grow more as a result. However, researchers did observe that when prairie dog colonies grew significantly (from 0-60% land cover) in a year, cattle mass gain decreased by 8% (Augustine & Derner, 2021). Approaching the issue from a different angle, Crow *et al.* (2022) used an economic model considering livestock, prairie dogs, plague death, and drought to evaluate different scenarios of prairie dog management and the resulting income changes for ranchers. Crow *et al.* (2022) found that when prairie dogs reduce overall forage but still provide grazing opportunities on their colonies, the cost of lethal control did not outweigh the benefits even when prairie dog populations grew during a drought. However, if prairie dog colonies prevented grazing opportunities for cattle, prairie dog expansion during droughts can cause significant economic damage to a ranch (Crow *et al.,* 2022). The first scenario is most applicable to a yearling style of cattle ranching, when the growing season is most important so cattle can still graze on colonies. The second and more concerning scenario can have serious implications, especially for cow-calf ranching, where cattle need year-round grazing opportunities even during the dormant season when colonies might not have available vegetation. Importantly, both of these studies determined that **precipitation patterns dictated the severity of prairie dog's negative effects more than their overall population size or colony size**, indicating that prairie dog control may not negatively affect cattle growth during non-drought years (Augustine & Derner, 2021; Crow *et al.,* 2022).

Conclusion

Black-tailed prairie dogs are a keystone species that strongly influence grassland structure, biodiversity, and ecological processes. Their burrowing, grazing, and foraging behaviors create heterogeneity in vegetation and soils that sustain a variety of plant and animal communities across the Great Plains. However, despite their ecological value, prairie dogs remain one of the most persecuted mammals in North America due to their perceived competition with livestock and agricultural interests (Whicker & Detling, 1988; Ceballos *et al.,* 2010). Understanding their ecological significance is critical for reconciling the dual goals of rangeland productivity and biodiversity conservation, particularly in landscapes such as the eastern part of Colorado state where agriculture and native prairie intersect.

Beyond their immediate physical effects, prairie dogs represent a functional **indicator of grassland stability and resilience**. Their colonies serve as ecological focal points where interactions among vegetation, soil, and wildlife are tightly linked, providing a living measure of the overall health of prairie ecosystems. As highly interactive species, their presence influences ecological feedback that regulate plant diversity, nutrient cycling, and trophic dynamics. This makes prairie dogs valuable for conservation planning because they integrate the effects of multiple environmental drivers, including climate variability, grazing intensity, and land-use change—within a single, observable system.

Prairie dog colonies also promote the long-term adaptive capacity of grasslands. By maintaining a mosaic of vegetation types and open ground, prairie dogs help buffer prairies against environmental fluctuations, allowing species with varying ecological niches to coexist. Their burrowing and grazing activities encourage rapid regeneration following disturbance and improve the spatial distribution of soil nutrients and moisture, contributing to ecosystem recovery after droughts or heavy grazing events. This dynamic interaction between disturbance and renewal forms the ecological foundation for grassland resilience across much of the western United States.

In this broader context, the conservation and management of prairie dogs hold significance that extends well beyond protecting a single species. **Maintaining healthy, connected prairie dog populations safeguards the ecological functions that sustain grassland productivity, biodiversity, and soil health.** Their survival is directly tied to the integrity of the entire prairie biome, making them not only an indicator of ecosystem condition but also a cornerstone for restoring balance between wildlife conservation and agricultural land use.

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2 RAPTOR ECOLOGY

COLORADO PRAIRIE RAPTOR COMMUNITY DYNAMICS

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Introduction

Raptors and diurnal birds of prey are a fundamental ecological aspect of prairie ecosystems in Colorado. For most raptor species, primary prey includes small rodents such as voles, mice, shrews, and prairie dogs. Prairie dogs play an important role in prairie ecosystems, acting as a keystone species owing to their importance within the food chain, as well as the impact that they have as ecosystem engineers. Because many ranches reside in the prairie, many ranchers view prairie dogs as undesirable due to their large-scale trimming of grazable vegetation. As a result, many ranching communities advocate for prairie dog management often via lethal control (Wilmer *et al.,* 2025). Because of this, there has historically been a division between agricultural communities and conservation organizations regarding prairie dog control (Wilmer *et al.,* 2025). The overarching aim of this project is to develop a management strategy that benefits all parties, allowing prairie dogs to continue their natural behaviors while also helping ranchers and agricultural communities to maintain their profits and livelihoods.

Herein, we explore the idea of leveraging raptors as a biological population control for prairie dog towns. Since raptors are a natural predator of prairie dogs, we consider how increasing the raptor populations within certain areas (*i.e*. near prairie towns) might act as natural population management. The goal of this chapter is to obtain a better understanding of the patterns and dynamics of the predatory raptors that exist in the short grass prairie ecosystem, as well as within managed agroecosystems. Understanding the habitat, feeding, and nesting preferences of various prairie raptor species, and how these species interact with the prey available in this ecosystem, will help us to determine which species might be most effective for prairie dog control, and what management strategies could be used to attract these species to prairie dog towns. *The main questions posed herein are:*

1) How do the behaviors and preferences of specific raptor species dictate their interactions with the short grass prairie and other agroecosystems?
2) How might different raptor species interact with artificial infrastructure designed to aid the predation of pests in agroecosystems?

By addressing these questions, we hope to provide insights into the dynamics of raptors that inhabit Colorado east of the continental divide (*e.g*., predation, hunting preferences, land cover preferences, interactions with artificial infrastructure). Furthermore, by conducting an extensive literature review of current available information and consolidating key findings into summary tables, we aim to provide useful resources for future projects in this region and for landowners, including which species are present in their region, and information on how artificial infrastructure could be used to attract species that benefit agroecosystems. In collaboration with ranchers and other rangeland stewards, this study highlights the ecological roles of birds of prey and explore how their presence may align with land management goals.

Our literature review resulted in the synthesis over approximately 40 peer-reviewed articles and reports. We categorized information into four overarching topics: (1) seasonality and migration, (2) habitat preferences, (3) predation of pest species in agroecosystems, and (4) interactions with artificial infrastructure. Within each category, we focused our review on 12 raptor species in Colorado: Red-tailed hawk (*Buteo jamaicensis*), American kestrel (*Falco sparverius*), Swainson's hawk (*Buteo swainsoni*), Rough-legged hawk (*Buteo lagopus*), Ferruginous hawk (*Buteo regalis*), Prairie falcon (*Falco mexicanus*), Bald eagle (*Haliaeetus leucocephalus*), Golden eagle (*Aquila chrysaetos*), Great horned owl (*Bubo virginianus*), American barn owl (*Tyto furcata*), Sharp-shinned hawk (*Accipiter striatus*), and Northern harrier (*Circus cyaneus*).

Seasonality and Migration

Migration, the movement of organisms from one geographical area to another, is a tendency found in almost all major animal groups. Some common examples are the monarch butterflies that travel from their breeding grounds in the northern United States to their wintering habitat in Mexico, or the caribou that migrate between the tundra and the montane regions of the boreal forest. This act of migration can be due to many causes, including seasonal breeding, changes in food availability, and climate and habitat preferences.

Understanding raptor seasonality and migration is vital when determining what infrastructure to implement if the main goal is increased raptor presence. Colorado has a diverse set of ecosystems, including short- and tall-grass prairies, riparian zones, and mountainous upland forests. Within each of these ecosystems, multiple species of raptors act as key predators. While some species are generalists in both habitat and prey, others have quite specific needs that they depend on. Because of this, the raptors in Colorado have a broad assortment of seasonal ranges, including continental migration, regional migration within Colorado or the United States, and non-migratory permanent residency in one area. Accordingly, we categorized the 14 raptor species into three types: migrational species, non-migrational species, and facultative or partial migrants (**Table 2.1**). The raptor species that seasonally migrate may be good species to focus on attracting due to their prey preference or habitat preference. However, because they are not in Colorado year-round, raptor perching infrastructure should not cater to the perching preferences of these species alone.

Table 2.1. Seasonality of raptor species in Colorado. Species with an asterisk (*) are raptor species that are present year-round within prairies in Colorado.

Seasonality	Birds
Present in Colorado in Winter (migrational)	Rough-legged hawk (*Buteo lagopus*)
Present in Colorado in Summer (migrational)	Swainson's hawk (*Buteo swainsoni*)
Present year-round across Colorado	American barn owl (*Tyto furcata*)* American kestrel (*Falco sparverius*) Bald eagle (*Haliaeetus leucocephalus*) Ferruginous hawk (*Buteo regalis*) Golden eagle (*Aquila chrysaetos*) Great horned owl (*Bubo virginianus*) Northern Harrier (*Circus hudsonius*) Prairie falcon (*Falco mexicanus*)* Red-tailed hawk (*Buteo jamaicensis*)* Sharp-shinned hawk (*Accipiter striatus*)

Migratory raptor species

In Colorado, there are three main migratory raptor species associated with prairie ecosystems: the Rough-legged hawk, Prairie falcon, and Swainson's hawk. While all of these species migrate, their migration patterns differ.

Rough-legged hawks spend the majority of the northern hemisphere summer in the Arctic tundra and winters in the lower 48. Migrating in the early spring from the temperate forest and arid grassland regions, the rough-legged hawk spends its breeding season on the cliffs of the tundra (National Audubon Society, n.d.). This migration is very important not just for breeding habitat but also for food availability. Rough-legged hawks are lemming specialists and one of the main predators for the collared lemming (Reid *et al.*, 1997; Beardsell *et al.*, 2016). While this species does make the trek from their winter grounds to their summer breeding habitat every year, the food availability once they have made it to the tundra will determine whether or not they breed that season (Reid *et al.*, 1997).

The ***Prairie falcon***, on the other hand, has a much shorter migration with its breeding habitat in the Rocky Mountains and the Great Basin, and its wintering habitat in the Great Plains (Beauvais *et. al.,* 2024). This species can be found in Colorado year-round; however, during the winter, it is only found in regions with short grass prairie and grasslands.

The ***Swainson's hawk*** has one of the longest migrations of raptor species present in Colorado. It breeds in western North America, primarily in montane regions including Colorado, and then migrates through central and South America, ending in central Argentina for their non-breeding season (northern hemisphere winter; Beauvais *et. al.,* 2024). All of these raptors can be found in Colorado, though they will only be seen at certain times of the year.

Non-migratory raptor species

The non-migrational species that are the most relevant in Colorado are the ***American barn owl, Bald eagle, Great horned owl, and Sharp-shinned hawk***. All of these species can be found within Colorado year-round, though a few of them are not common grassland or prairie dwellers. The Bald eagle, Sharp-shinned hawk, and the Great horned owl are not common prairie predators unless there is a large swath of riparian or forested habitat nearby. The American barn owl is a resident non-migrational species (National Audubon Society, nd) that's only requirement is to be near a suitable foraging habitat when breeding (*i.e.*, short grass prairie, agricultural area, hayfields, grasslands; Hindmarch *et al.*, 2012). All of these species are present throughout Colorado year-round, making them good species to focus on when attempting to increase raptor populations, depending on habitat type.

Partial or Facultative migrants

The last category for seasonality is facultative or partial migrant, meaning that certain populations will migrate between breeding seasons to follow food sources, while other populations will remain in one region or territory. The majority of the raptor species that this paper focuses on are partial migrants. While all of these species are permanently present in Colorado, they also all have populations that migrate seasonally. The ***American kestrel*** is a great example because, in some areas like New Mexico, it is known to migrate between low and high elevations; however, it is present in agroecosystems and the short grass prairie in Colorado all year round (Stahlecker & Cartron, 2010). The ***Northern harrier*** has breeding habitat in most of Canada, Alaska, and the north-central and north-eastern United States, along with non-breeding habitat in the Southern U.S., Central America, and select Caribbean islands (Smith *et al*., 2020). While the Northern harrier has populations that migrate between these two areas, it also has individuals that are present year-round in the western U.S. (Smith *et al*., 2020). The ***Golden eagle***, though permanently found in Colorado year-round, has slightly different partial migration patterns. Its migrational behaviors are based on its life stage, where, during different life stages, it is non-migrational, migrational, or adolescent (Brown *et al*., 2017). The ***Red-tailed hawk***, the most common hawk in North America, can be found all year round in most of the U.S. and Mexico, and parts of Central America. It has breeding locations in central and southern Canada and parts of Alaska, but it can be found in Colorado year-round (National Audubon Society, nd). Finally, the Ferruginous hawk is a short to medium distance migrant with breeding grounds in Montana, Wyoming, Nevada, Utah, western Nebraska, Idaho, Eastern Washington and Oregon, and North and South Dakota, and its non-breeding time in Mexico, Texas, Southern New Mexico and Arizona, and California (Ng *et al.,* 2020). Even with its distinct breeding and non-breeding regions, it can also be found in all seasons in eastern Colorado and parts of Utah, New Mexico, Arizona, Kansas, Nebraska, Montana, and South Dakota (Ng *et al.,* 2020). Understanding that all of these birds can be found year-round in Colorado, but also have migrating populations, is very important when determining how raptors can be used as population controls on agricultural pests. With the constant presence of these raptors in Colorado, they are good targets to aim for when implementing infrastructure designed to increase raptor presence. Because there are also migrational populations, it is important to understand that the relative abundance of these species may change throughout the year.

Habitat Preferences of Eastern Colorado Raptors

Raptors are wide-ranging species, each with distinct habitat preferences, ecological niches, and resource requirements. Of the twelve raptors studied, all demonstrated variation in habitat use. Across this study's chosen spatial extent, within Colorado, east of the continental divide, the raptors analyzed inhabited four general habitat zones: prairie (both short- and mixed-grass), croplands and areas of low development, uplands including tundra, montane, and riparian systems, and forested foothill regions (Table 2.2). Multiple factors influence why a raptor species may favor one habitat type over another, including prey availability and composition, hunting strategies, and the availability of suitable nesting, roosting, and perching structures (Atuo & O'Connell, 2017).

Most of the raptors studied, including the American Kestrel, Ferruginous Hawk, Red-tailed Hawk, Prairie Falcon, Golden Eagle, Northern Harrier, Swainson's Hawk, and Rough-legged Hawk, prefer to hunt in areas with open sight lines but depend on perches, cliffs, or trees for resting and nesting (Table 2.3). This creates limitations for which species can thrive in contiguous prairie regions, despite these areas offering ideal hunting grounds for preferred prey. Nearly all species require elevated structures such as tall trees or cliffs, or alternatively, manmade features, including abandoned farm buildings, telephone poles, and cell towers for roosting and nesting.

Table 2.2. Raptor species that occupy each of four unique habitat zones in Colorado. Some species occupy more than one habitat type.

Habitat Type	Raptor species present
Prairie: short and mixed-grass	American kestrel, ferruginous hawk, red-tailed hawk, prairie falcon, golden eagle, northern harrier, Swainson's hawk, rough-legged hawk
Croplands and low development	Ferruginous hawk, American kestrel, red-tailed hawk, rough-legged hawk, Swainson's hawk, prairie falcon, northern harrier, barn owl
Uplands: montane, riparian, tundra	American kestrel, golden eagle, northern harrier, bald eagle, prairie falcon, great horned owl, red-tailed hawk, rough-legged hawk
Forested foothills	American kestrel, red-tailed hawk, bald eagle, golden eagle, sharp-shinned hawk, great horned owl, American barn owl

Although the rangelands of eastern Colorado, in which our study is focused, provide excellent hunting opportunities for many raptors, the limited availability of suitable perching and nesting infrastructure constrains their population density. Consequently, raptors in these landscapes are frequently observed using human-made structures as perches (Atuo & O'Connell, 2017; Zagorski & Swihart, 2021; Wiggins *et al.,* 2014; Inselman *et al.,* 2016). In this context, raptor abundance in eastern Colorado agroecosystems appears to be shaped more by landscape structure than by prey availability, aligning with Atuo and O'Connell's (2017) findings that structural heterogeneity strongly influences raptor assemblages in mixed-grass ecosystems.

Table 2.3. Raptor species categorized by their nesting behavior. Note that some raptors exhibit two or more of these nesting behaviors.

Nesting Behavior	Raptor species
Nest builders (in trees or tall manmade structures)	Prairie falcon, golden eagle, ferruginous hawk, red-tailed hawk, rough-legged hawk, Swainson's hawk, bald eagle, American barn owl, great horned owl, sharp-shinned hawk
Cavity nesting	American kestrel, red-tailed hawk, prairie falcon, American barn owl, great horned owl
Ground nesting	American kestrel, golden eagle, ferruginous hawk, northern harrier, red-tailed hawk, American barn owl, great horned owl
Cliff nesting	American kestrel, prairie falcon, red-tailed hawk, rough-legged hawk, ferruginous hawk, golden eagle, sharp-shinned hawk, great horned owl, American barn owl

Predation of Pests by Raptors in Agroecosystems

Colorado raptors have a variety of unique foraging strategies and prey preferences, making the synthesis of raptor hunting a complicated endeavor. For the purposes of this section, we decided to isolate six raptors whose predation habits make them promising candidates for biological pest control, especially against black tailed prairie dogs. These raptors are the Red-tailed hawk, Ferruginous hawk, Swainson's hawk, American kestrel, and the Golden eagle.

Three of the five raptors identified, Red-tailed hawk, Swainson's hawk, and Golden eagle, can be loosely categorized as generalists. These raptors are known to consume a wide variety of prey and, for the most part, consider prairie dogs a secondary food source to more desirable species. ***Red-tailed hawks*** are perhaps the most indiscriminate and adaptable of these raptors. While they are known to prey on prairie dogs, they are not reliant on their populations for survival, consistently maintaining abundance in the absence of active prairie dog colonies (Merriman *et al.,* 2007). While not exclusively targeting species detrimental to agriculture and ranching, they do prey on several pests including insects such as grasshoppers, small mammals, and occasionally reptiles (Fitch *et al.,* 1946). Like most prairie raptors, red-tailed hawks are sit-and wait-predators. They prefer to ambush prey from perches and spend most of their time waiting atop fence posts, trees or other areas with high vantage points (Leyhe & Ritchison, 2004).

Swainson's hawks are similar to Red-tailed hawks but have a specific affiliation with open ecosystems such as the prairie. Swainson's hawks also prey on primarily small mammals and not insignificantly, insects, reptiles and amphibians (Giovanni *et al*., 2007). These hawks show a high preference for low vegetation areas, often foraging in recently grazed or harvested fields within agroecosystems (Inselman *et al.,* 2016). Although no study within this literature review explicitly quantified it, several research papers implied Swainson's hawks to be perch hunters and one even suggested that perch availability could contribute to their foraging success (Inselman *et al.,* 2016). Golden eagles are among the more unique raptors in this literature review. For starters, these raptors focus more on mammals then the other two generalists, and usually larger mammals such as rabbits (Brown *et al.,* 2017). Prairie dogs are a secondary but not infrequent source of food for ***Golden eagles*** especially in the winter months when they migrate to the plains and in drought years when other species are less abundant (Brown *et al.*, 2017). Unlike Swainson's hawks and Red-tailed hawks, Golden eagles are frequent "on wing" hunters, meaning they mainly hunt from the sky (usually on a thermal) as opposed to a perch (Brown *et al*., 2017). That said, Golden eagles do have some perching tendencies while hunting but they usually gravitate more towards higher perches such as telephone lines and wind turbines over fence posts (Brown *et al*., 2017).

With the understanding that all these raptors are being considered for their pest management ability, the American kestrel and Ferruginous hawk may be considered specialists, as they often prey on unwanted species in agriculture.

The ***American kestrel*** is the smallest raptor identified in this literature review so unsurprisingly, a large portion of its diet (around 71% but variable depending on region) consists of invertebrates (Stahlecker & Cartron, 2010). In the American southwest, kestrels forage in open spaces with low vegetation cover and spend up to 93% of their time perching (Stahlecker & Cartron, 2010). American kestrels are uniquely situated in prairie ecology. Their hunting strategies are similar to larger raptors, but, at the same time, many of these raptors are also predators of the kestrel. The presence of American kestrels could both control invertebrate populations and attract raptors higher in the food chain, potentially contributing to an overall healthier and more diverse ecosystem.

In terms of prairie dog management, the ***Ferruginous hawk*** shows the greatest potential. The Ferruginous hawk has a strong preference for prairie dogs. One study showed that the bulk of ferruginous hawk prey biomass was prairie dogs (Giovanni 2007) while two separate studies found increased breeding density and nesting success for ferruginous hawks within 2-km of an active prairie dog town in Oklahoma and New Mexico (Cook *et al.* 2003; Smith and Lomolino 2004). Additionally, ferruginous hawks prefer to hunt in areas of even lower vegetation than Swainson's hawkswhich correlates with grass cover trends around prairie dog colonies (Wakeley, 1978). Similar to other prairie raptors, ferruginous hawks are frequent sit and wait ambush raptors perching anywhere between 10-100 meters from potential prey. However, Wakeley (1978) observed limited success from perch hunts by two male ferruginous hawks. Instead, ferruginous hawks most often captured prey from high flight or directly on the ground outside of animal burrows (Wakely, 1978). Considering the small scope of the study and absence of similar research, conclusions from this information should be taken with consideration.

Each of the six raptors identified fulfills a distinct niche in the agroecosystems of Colorado, but there are some common threads to note. First, as previously stated, many raptors prefer to forage in open spaces whether that is recently grazed land, open prairies, or harvested crop fields. Second, all raptors use perches especially when foraging. Most of the literature suggested greater hunting success for raptors with the presence of perches in agroecosystems. These commonalities aside, it's worth noting that no singular raptor can fulfill all pest management needs nor should it. A combination of raptor species will benefit agroecosystems by encompassing more niches and contributing to greater raptor abundance.

Raptor Interactions with Artificial Infrastructure

Limited research exists on how specific raptors interact with infrastructure designed for perching or nesting, but inferences can be made based on raptor habits and history with anthropogenic activity and structures. For this literature review, we consolidated information that could help researchers and interested landowners make informed decisions on artificial infrastructure implementation. Since some of the literature suggested that a few of the raptor species rarely interact with anthropogenic structures due to either preference for hunting on wing or preference for habitat with more natural perches and nesting locations, we focused on five raptors that have both (1) historically utilized anthropogenic structures and (2) prey on species undesirable in agriculture and ranching, particularly within the prairie (Table 2.4). These species include: the Red-tailed hawk, Ferruginous hawk, Swainson's hawk, American kestrel and Golden eagle.

The *red-tailed hawk* stands out as one of the most tolerant raptors to anthropogenic activity in the prairie. In addition to being known perch hunters, red-tailed hawks show a high tolerance (up to 30%

of their territory) for living and hunting in anthropogenic spaces (Berry *et al.,* 1998). This, combined with their generalist hunting preferences and persistence through prairie dog population fluctuations, could make them a reliable addition to agroecosystems and willing users of artificial raptor perches (Leyhe & Ritchison, 2004; Merriman *et al.,* 2007).

Table 2.4. Perching habits, prey preferences, and sensitivity to anthropogenic disturbances for five raptors known to interact with artificial infrastructure. For each raptor, the statement in the column is described as True (XXX), somewhat True (XX), infrequently true(X), or untrue (-). Assessments are based on literature review.

Raptor Species	Perch hunter	Preys on prairie dogs	Preys on small rodents (- prairie dogs)	Preys on Insects	Sensitive to anthropogenic disturbances
Red Tailed Hawk	XXX	X	XX	X	X
Ferruginous Hawk	XX	XXX	X	X	XXX
Swainson's Hawk	XX	X	XX	XX	X
American Kestrel	XX		X	XXX	X
Golden Eagle	X	X	X	-	XX

True: XXX Somewhat True: XX Infrequently True: X

Similarly tolerant to anthropogenic activities are ***American kestrels***. These invertebrate hunters can also tolerate up to a third of their territory in cultivated land (Berry *et al.*, 1998). Additionally, American kestrels are secondary cavity nesters and may consider using nest boxes within the prairie (Stahlecker & Cartron, 2010). Even if not used for nesting, kestrels may benefit from nest boxes by eating nestling songbirds that take up residence in them (Stahlecker & Cartron, 2010). Due to their sit and wait hunting strategy, they would likely benefit from more locations to perch on the prairie and could be targets for raptor poles. As previously expressed, there is also potential for kestrels as both predator and prey in agroecosystems. Their presence may control invertebrate populations while attracting larger raptors. When beginning to create agroecosystems attractive to raptors it may be beneficial to initially target American kestrels before creating infrastructure for larger raptors.

Swainson's hawk is the last of these five raptors to show substantial tolerance to anthropogenic activities. Their nests are often found along roadsides and around homesteads (Inselman *et al.,* 2016). Moreover, Swainson's hawks not only tolerate but benefit from a diverse territory that encompasses cropland and grassland (Wiggins *et al.,* 2014). As perch hunting raptors that exist primarily in the prairie, they would almost undoubtedly benefit from raptor poles. This is reaffirmed by their known perching habits on infrastructure such as telephone poles, fence posts, and homestead trees, which are all adjacent to human activity and infrastructure (Inselman *et al.,* 2016). Similar to red-tailed hawks, Swainson's hawks are generalists, but they are more prairie specific. Swainson's hawks may be more inclined to nest and hunt in the prairie than a species like the red-tailed which can exist in a greater range of habitats.

Golden eagles may have the most specific needs of any of these raptors. Literature on golden eagles describes willing use of human infrastructure, yet negative resulting interactions with infrastructure. Collisions with power lines and wind turbines, in particular, are of major concern (Brown *et al*., 2017). Though they are frequent perchers, the literature implies a preference for taller structures than what most raptor poles provide. Along the same lines, golden eagles usually nest in cliffs or ridges not found in the prairie, making them poor candidates for nesting infrastructure (Brown *et al*., 2017). Although they are prairie hunters, these factors, along with the proportionally low abundance and on wing hunting strategy, make golden eagles a difficult raptor to target for artificial infrastructure (Brown *et al.*, 2017). These raptors may be more inclined to visit an already healthy agroecosystem than pioneer it.

As the raptor with the most potential to control prairie dog populations, the ***Ferruginous hawk*** is among the more sensitive of these raptors to anthropogenic disturbances. Unlike the generalist raptors, the ferruginous hawk has been recorded leaving nests after encountering disturbances such as loud farm equipment (Schmutz, 1989). Additionally, they are found in greatest abundance in protected lands away from human activity (Wiggins *et. al*, 2014). Barring the anthropogenic aspects of agroecosystems, these regions make otherwise practical nesting and hunting grounds for ferruginous hawks. Preferring barren or heavily grazed land cover for hunting and nests within 2-km of active prairie dog colonies, a thoughtfully placed nesting platform or perch may have the potential to attract ferruginous hawks (Wakeley, 1978; Cook *et. al*, 2003; Smith and Lomolino, 2004). In some prairie dog abundant non-agricultural regions, Ferruginous hawks already use artificial nesting platforms, suggesting their potential in agroecosystems (Wiggins *et. al,* 2014). Ferruginous hawks may respond best to isolated perches and nesting platforms in grazing lands with low human disturbance. Their interactions with nesting platforms suggest it may take a while before they use the infrastructure, but once established, may consistently return to those sites.

Synthesis of Findings & Existing Gaps in Understanding

This study synthesizes existing literature on raptor ecology in Colorado east of the Continental Divide to identify species most likely to serve as biological controls for pests in agroecosystems. However, due to its broad nature, we were unable to draw definitive conclusions about how artificial raptor infrastructure might be used. Still, this review makes inferences about which raptor species may be of greatest interest to landowners and ranchers considering prairie dog population control. Ferruginous hawks emerge as the species most strongly associated with prairie dog predation (Smith and Lomolino,2004), while Swainson's hawks (Inselman *et al.,* 2016), American kestrels (Stahlecker & Cartron, 2010), red-tailed hawks (Berry *et al.,* 1998), and prairie falcons (Beauvais *et al.,* 2024) are most likely to utilize artificial raptor poles. These findings provide guidance for landowners and ranchers interested in leveraging natural predation to manage prairie dog populations while supporting local biodiversity. Beyond immediate agricultural applications, this research also highlights broader ecological implications. Raptors are key predators in shortgrass prairie ecosystems and contribute to the regulation of prey populations. Prairie dogs, as keystone species, influence vegetation structure and provide habitat for other wildlife; promoting raptor predation on prairie dogs in a controlled, landscape-sensitive way may support both ecosystem function and ranching goals.

This work also identifies substantial gaps in landscape-level understanding of raptor ecology, including raptor abundances, seasonal dynamics, and interactions with artificial perches. Addressing these gaps through long-term monitoring, wildlife cameras, and comparative studies could inform multi-species management strategies and contribute to regional conservation efforts. Implementing raptor-friendly infrastructure in rangelands offers a practical example of integrating ecological knowledge with natural resource management, reinforcing the importance of structural heterogeneity and species diversity in maintaining resilient agroecosystems.

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3 RAPTOR POLES

RAPTOR POLES AS A TOOL FOR BIOLOGICAL CONTROL IN GRASSLANDS

Josie Kirley, Gabby Marchant, Owen Wyman

Grassland prairie ecosystems are increasingly fragmented by the expansion of agricultural production farmlands, which isolates habitat patches and reduces connectivity for vulnerable species (Salas *et al.*, 2024). Species abundance can be influenced by landscape setting, especially considering urbanization causing habitat-quality and quantity reduction between patches (Berry *et al.*, 1998). This increases distance and decreases connectivity between preferable and available habitat areas, limiting genetic flow and diversity drastically. The western edge of the Great Plains along the eastern front of the Rocky Mountains in Colorado were historically a heterogenous mixture of mixed-grass prairies and riparian wetland corridors, transformed and threatened presently due to suburban expansion in areas of Fort Collins south to Colorado Springs (Berry *et al.,* 1998). This threatened landscape of Colorado supports predator-prey dynamics between birds of prey and prairie dogs whose habitats make up the grassland prairie environments. To connect these complex ecological processes, we must place these interactions in the context of fragmentation and human interference that alter these processes for many species over many different landscapes.

Prairie dogs are considered keystone species within grasslands (Kotliar *et al.*, 1999), and through their crucial alteration to their environments such as soil nutrient cycling, burrowing, and clipping, they significantly alter vegetation spatial structure and productivity, soil, and promote an increase in biodiversity (Cook *et al.,* 2003). Burrows also serve as shelters from predation for other rodents, insects, and other birds in the open landscapes of the prairies (Cook *et al.*, 2003). Threats to prairie dog population ranges and densities examined over a 120-year timeline show a steady decline and reduction to species abundance (decline of >95% of prairie dogs from 1900-1990) due to anthropogenic causes (Salas *et al.*, 2024). Not only are habitat loss and fragmentation impacting both raptor species and prairie dogs, but many public and private landowners subsidize methods of 'pest control' to deter colonies from settling and directly control mortality rates both lethally and nonlethally, a strategy upheld throughout the western United States (Salas *et al.,* 2024). Declines in prairie dog rodent populations directly impact raptor food availability as well as mortality, and there is currently a lack of research that connects evidence of toxins used for prairie dog mitigation to poisoned raptors (Salas *et al.*, 2024).

Birds of prey within the North American Southwest travel in low densities and have extensive home ranges. Accordingly, they are affected by declines of prey availability that increase travel distance between prairie dog colonies (Berry *et al.,* 1998). North American grassland bird populations have declined by up to 53% since 1970, creating urgency to identify ecological management strategies that sustain these populations and support the few remaining higher-quality fragments (Salas *et al.,* 2024). Raptors that migrate seasonally after the breeding season are at highest risk when navigating unfamiliar and fragmented landscapes and may spend increased periods of time sourcing resources for prey or habitat, further elevating the risk of threats within human-modified landscapes. This points to the overall importance of reliable sources of food, such as colonial rodents, that are relatively stable in both space and time in these grassland ecosystems throughout seasonal and annual fluctuations (Salas *et al.*, 2024). The reduction of suitable raptor hunting conditions by monocrop farming facilitates large outbreaks of rodent populations, further harming rangelands (Beltramo & Goudet, 2025). The complex dynamic between ranchers' agricultural needs and the presence of prairie dogs creates a challenge for conservation and management in these landscapes. Despite prairie dogs' key ecological impacts (Cook *et al.*, 2003), ranchers experience problems including reduced vegetation availability for grazing and increased disturbance to their agricultural production (Salas *et al.*, 2024).

Installation of raptor poles in areas void of natural perches may encourage predation, reducing prairie dog impact on Colorado's ranch lands. Raptor consumption of vertebrates in the region poses a solution to rodent pests for landowners and crop producers. (Kross *et al.,* 2024). Research on raptor utilization of artificial perches has been studied historically; nevertheless, relevant data are limited (Beltramo & Goudet, 2025). For this study, five private conserved ranchland properties in southeastern Colorado implemented raptor poles to assist ranchers in prairie dog population control through a cost-effective management approach. Across the five properties, a total of 20 raptor poles were installed, with varying combinations of nest boxes and control methods. Nest boxes were installed at two of the five properties to promote more permanent raptor presence, while the remaining properties implemented only raptor poles. Mechanical control via firearm use is currently utilized at some locations, and some landowners agreed to suspend or avoid chemical baiting during the study period. Overall, these sites reflect a broad interest in biological prairie dog control through raptor attraction, with poles consistently adopted across diverse management contexts. Preservation of large open spaces within urbanized landscapes (Berry et al., 1998), as well as agricultural plots that limit urban development on private lands such as the five mentioned ranches, are crucial areas for disturbance-resilient species such as birds of prey, even more so with the presence of prairie dog towns that exist as food sources.

Focusing on the interactions between prairie dogs and raptors in the shortgrass prairies, we sought to better understand specific ecological processes that occur in the context of recently installed artificial raptor perches. Through synthesizing existing research, we aimed to gain insight into how these raptor poles influence prairie dog behavior, abundance, and population dynamics of their colonies, as well as facilitate a balanced predator-prey relationship between raptors and prairie dogs.

Our three guiding research questions were:

1. How do artificial raptor poles affect raptor abundance and behavior?
2. How do raptors affect prairie dog presence, behavior, and population dynamics?
3. How can artificial raptor poles be used as a biological pest control to control prairie dog behavior and population dynamics?

Effect of artificial raptor poles on raptor abundance and behavior

Artificial perching poles, or raptor poles, are tall human-made structures that provide a predatory vantage point and resting space for raptor species where natural perches like trees do not exist (University of Wisconsin-Madison, 2016; Structures for Wildlife, 2023). Raptor poles provide immediate and longer-term benefits, encouraging raptor hunting success through increased roosting, nesting, and feeding behavior in an area, and providing ecosystem services such as toxin-free rodent and snake population control and crop protection in agricultural areas (Martinico, 2023). Introduction of poles to a landscape encourages raptor presence and creates a corridor for vulnerable birds of prey in fragmented landscapes. Landing areas are important for many raptor species, such as falcons, hawks, eagles, kestrels, owls, and more, each with different migratory patterns, hunting requirements, and nesting preferences (Cotton, 2018).

Despite differences in hunting and habitat preference between diurnal and nocturnal bird species (Beltramo & Goudet, 2025), success has been reported in studies that show birds utilize artificial perches in a variety of their preferred habitats, and that fields with perches have higher densities of raptors present (Cotton, 2018; Martinico, 2023). Installing raptor perches increases raptor presence, hunting events, and reduces rodent populations, and remains an understudied method to reduce environmental harm compared to other methods. States with high agricultural yield around the country (*e.g.*, Colorado and New York) have placed perches surrounding their crops of melons, grapes, fruit, and organic products to control the presence of smaller bird species and rodent species (Cotton, 2018). Raptors frequently used perches in irrigated pastures and sloped areas, and increased perch use may be associated with greater prey availability, favorable flight conditions such as updrafts, and a lack of nearby natural perches (Kross *et al.,* 2024).

Placement of artificial perches to increase raptor abundance

When constructing artificial perches, determining placement requires a strong understanding of local biological processes and raptor territorial behavior in order to encourage the highest raptor presence at each pole. Selecting locations based on factors such as rodent populations, prey abundance, habitat availability, topography, and the historical presence of raptors is of high importance (Cotton, 2018; Structures for Wildlife, 2023). **Placement of poles should be within 200-ft of cropland perimeters, with a minimum of two perches per acre and one pole per five acres of land on average,** keeping spatial scale in mind for larger areas. (Cotton, 2018; Martinico, 2023; University of Wisconsin-Madison, 2016). Perches placed on the highest points of a landscape (hilltops and ridges) will see the greatest raptor presence and usage, as well as areas with higher grassland vegetation. Installation can occur throughout the year, except during breeding season to avoid interference with breeding behaviors of juveniles or adults (Martinico, 2023; Structures for Wildlife, 2023).

Perches are to be set at heights between 12-20 ft above ground, with many variations in designs (**Figure 3.1**; University of Wisconsin-Madison, 2016; Cotton, 2018; Kross *et al.,* 2024; Beltramo & Goudet, 2025). The height of poles determines the distance a raptor can see and hunt at, meaning heights 15-20 ft above ground are ideal (Cotton, 2018). Raptor poles can be attached to existing modified fence posts to increase perch availability in rangelands with rocky soils, possibly a cost-beneficial strategy for ranchers in western North America. Poles must be anchored with a stable, weatherproof method in the ground, such as an existing fencepost or with concrete at 3-6ft in depth (**Figure 3.2**; Kross *et al*., 2024; Cotton, 2018). Perches are typically made from galvanized steel poles (at least 1 ½" diameter) or untreated weather-resistant wood such as cedar, cypress, redwood, or pine (at least 3-4" diameter). Recycled utility poles may be used if confirmed to be free of toxic treatments. All hardware, including nails, screws, and hinges, should be rust-proof to ensure long-term durability in outdoor conditions (Structures for Wildlife, 2023). The structure at the top of the pole must be a wooden crossbar perch (with optional rounded edges) of a minimum size of 2 ft in length and 2" by 2". Crossbar lengths depend on the size of the raptor species in the area, ranging from 1.5-inch by 2x4 or 2x6. The orientation of the pole should face the east-west direction as this position offers the most available light for perched raptors, benefiting their hunting efforts (Cotton, 2018). Wooden support boards attached diagonally from the end of the horizontal cross bar to the vertical pole, as well as an additional horizontal perch located 3 ft below the top bar (Cotton, 2018; Kross et al., 2024; Structures for Wildlife, 2023).

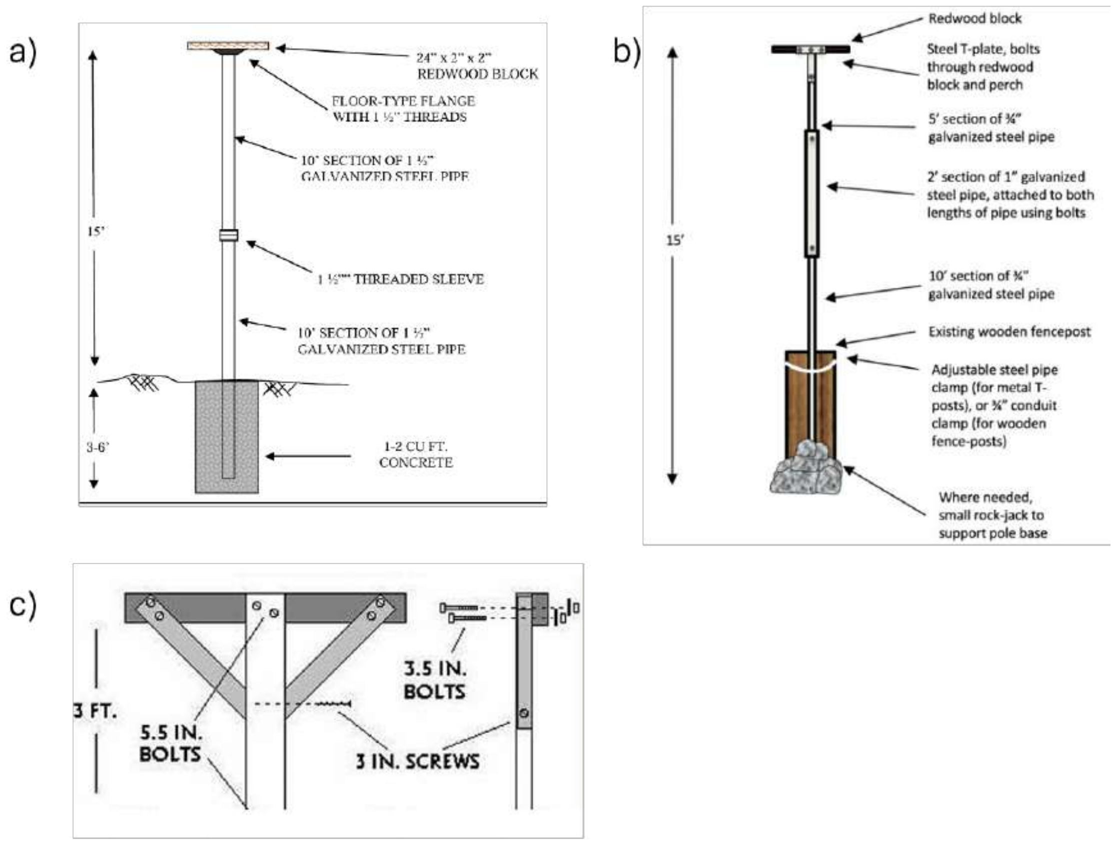

Figure 3.1. Perch design examples. (a) Perch design using concrete; (b) perch design for areas with rocky soils (*From* Structures for Wildlife, 2023); (c) perch design with wooden support boards attached to a steel or wooden pole base (*From* Structures for Wildlife, 2023).

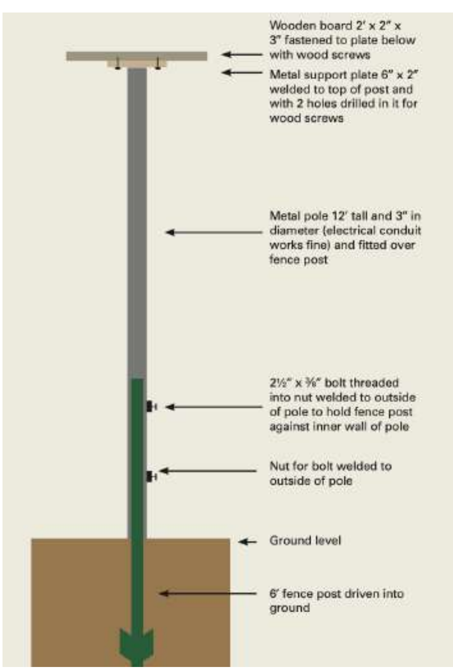

Figure 3.2. Raptor perch design, with measurements of materials, attached to an existing fence post (*From* Cotton, 2018).

Poles should not be obstructed by objects in order to minimize deterrence from landing in these areas (Figure 3.3). Additionally, poles are not to be installed within 200 ft of paved roads or within ¼ mile from a multi-lane highway or freeway to mitigate endangered species and further limitations on use. It is recommended to avoid installation in areas 200-ft from a nesting box, and to be aware of perches placed in native grasslands to minimize threats and competition for nesting and brooding of bird species of high conservation concern (Structures for Wildlife, 2023).

In relation to prairie dogs, placement of perches for hawks in proximity to colonies provides a natural ecological balance of predator and prey species. Specifically for rodent control on crop-producing land, a galvanized pipe base (¾-inch to 2-inch thickness) is recommended, preventing smaller animals from climbing the structures. Thicker poles (8 inches to a foot in diameter) are needed for high cattle activity and grazing areas that may need to withstand scratching on and general movement (Cotton, 2018; Kross et al., 2024). In general, making sure placement of perches is viable for a certain area remains important when considering populations of threatened species such as the sage grouse that may decline with increased raptor presence (Cotton, 2018).

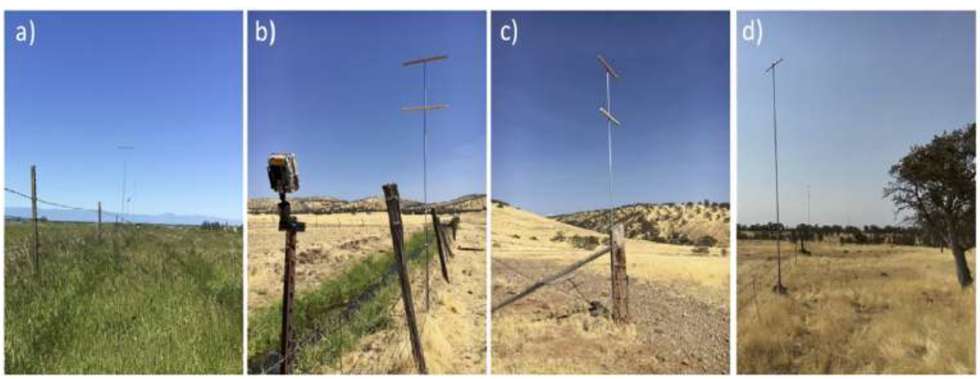

Figure 3.3. Four perch designs in different habitats: (a) 4.5 m (15') tall perch with one crossbeam in irrigated pasture habitat; (b) 4.5 m (15') tall perch with two crossbeams in Lowland Savannah habitat; (c) 4.5 m (15') tall perch with two crossbeams in the Upland Savannah habitat; and (d) 6.1 m (20') tall perch with one crossbeam in Oak Woodland habitat. (From Kross *et al.*, 2024).

Effect of raptors on prairie dog presence, behavior, and population dynamics

Raptors and prairie dogs exhibit a crucial predator-prey dynamic, a relationship that maintains ecological balance to control prey overpopulation, overgrazing, and resource depletion. Research has shown that raptors affect prairie dog populations both directly through predation and indirectly by altering behavior and habitat use.

Raptors directly affect prairie dogs through their rodent predation. One study in Fort Collins explored raptor use of artificial perches near black-tailed prairie dog colonies (Witmer *et al.*, 2008). A wide variety of raptors were observed using the perches, including red-tailed hawks, ferruginous hawks, and bald eagles (Witmer *et al.*, 2008). Through an analysis of regurgitated pellets, it was found that these raptors were consistently eating prairie dogs (Witmer *et al.*, 2008). This study found that the relationship between the number of raptor pellets and prairie dog presence was inverse, meaning areas where more raptor pellets were found, there were fewer prairie dogs. This pattern suggests that raptors were actively preying on prairie dogs, and therefore, this predation may slow prairie dog colony expansion. The study also mentioned that solely raptor predation is unlikely to completely control prairie dog populations, but could be a useful component to managing them (Witmer *et al.,* 2008)

Building on this, there have been surveys completed that looked at plots with and without prairie dog colonies and compared the two to understand raptor abundance based on prairie dog presence (Merriman *et al.* 2007). Through this process, it was found that certain raptor species, such as Ferruginous Hawks and Northern Harriers, were more abundant at the plots with prairie dog colonies (Merriman *et al.* 2007). Comparatively, other species of raptors, such as Kestrels and Swainson's Hawks, were observed to be more abundant at non-prairie dog plots (Merriman *et al*. 2007). These findings are relevant because they demonstrate that prairie dog colonies not only provide a food source for raptors but also shape the overall composition and distribution of raptor communities across grassland ecosystems.

Other research has found evidence that supports raptors using prairie dogs as a significant food source. One study from Oregon State found that a family of barn owls can eat about 3,000 rodents per year; while an adult barn owl can eat approximately 10 to 12 per night during brooding (Oregon State, 2012). Other raptor species show a preference for prairie dogs as their prey, and even more so in the winter months when food is much scarcer (Oregon State, 2012). In Denver, a series of studies were conducted observing raptor activity near prairie dog colonies. It was observed that near these colonies, raptor activity was consistently very high; data showed that during some hours, six to seven raptors would be hunting near prairie dog colonies (Weber, 2007). This shows that prairie dog colonies can act as crucial foraging spots for raptors when food is limited during colder months.

Research has shown that prairie dogs are essential for a number of raptor species, and are a particularly important food source in the winter. Salas *et al.* (2024) examined overwintering raptor abundance and community composition across prairie dog colonies in the southern and central Great Plains and found that there was a positive co-occurrence between prairie dog abundance and overwintering raptors, which signals that prairie dog colonies are crucial for raptors. Cook *et al.* (2004), in a field study assessing ferruginous hawk nesting success in relation to prey availability in New Mexico, found that the nesting success of ferruginous hawks was significantly higher near prairie dog colonies. Specifically, hawks that were nesting within 2-km of the prairie dog colonies had greater reproductive success and also had more prairie dogs in their diets (Cook *et al*., 2004). This indicates that the amount of prey available influenced nest productivity. This points to the importance of maintaining prairie dog colonies for raptor conservation.

While there have not been many studies carried out to observe the indirect effects of raptors on prairie dogs, there is some evidence to suggest that prairie dogs show signs of alertness and other anti-predator behaviors from raptor presence alone. Witmer *et al.* (2008) found that more consistent raptor activity influenced prairie dog behavior by reducing the amount of time that they forage and spend aboveground.

Prairie dogs have very good alarm-call systems and level of awareness. They can recognize and react to alarm calls even from unfamiliar prairie dogs, which causes them to change their behavior. This may cause them to stop foraging and become more alert when they sense danger (Connell *et al*. 2019). For example, Connell *et al*. 2019 conducted an experiment that showed that when black-tailed prairie dogs alarm calls were played back to them, there was a significant decrease in the time that they spent foraging aboveground. This suggests that even indirect signs of predators, such as calls or movement, can cause prairie dogs to spend less time above ground or shift where they dig burrows, which can influence how their colonies grow and spread.

Use of artificial raptor poles as a biological control for prairie dog management

The use of raptor poles in short grassland ecosystems poles has the potential to effectively, sustainably, and passively alter the behavior and population of prairie dogs to benefit landowners and conservationists' shared goals. Although there is limited research on how the use of raptor poles directly affects prairie dogs, we aimed to make inferences about the available research to inform future studies and management techniques.

Ronen *et al*. *(*2024) demonstrated the effectiveness of using artificially installed perches to limit population size in rodents. They found that artificial perches increased the presence and hunting frequency of raptors. This led to rodent population suppression equal to using chemical pest control (Ronen *et al*. 2024). Similarly, a long-term study by Bontzorlos (2024) displayed an increase in owl populations on farms through the introduction of nest boxes. This was very beneficial for the reduction of rodent populations (3,000–4,000 prey items annually) and results displayed economic savings and reduced crop damage on the farms (Brontzorlos 2024). These two studies both offer practical results on the effects of artificial perches, as well as nesting boxes used in reducing rodent populations and abundance for landowners' benefits. They also confirm that the introduction of raptor poles can increase the presence and hunting frequency of raptors.

Raptor poles also have behavioral effects on prairie dog populations. Macher (2017) looked at the effects of raptor poles on vole populations and determined that, despite minimal recorded predation, vole density and drop damage decreased because of the "landscape of fear" effect (Macher 2017). Even just the presence of predators in the area causes behavior changes such as reduced surface activity, less foraging, and potentially lower reproduction rates due to stress or reduced feeding time. This has the potential to lower the population of the colony on larger time scales. Connell *et al*. *(*2019) noted increased vigilance of prairie dog populations with avian predators nearby. The colonies communicated with each other more using alarm calls and sentinel guards to identify predator threats, leading to a reduction in surface activity and foraging (Connell *et al*. 2019). These results are promising proxy studies to suggest that raptor poles can be used as an effective behavioral suppression of prairie dogs.

There are also some notable limitations to using raptor poles as a biological pest control. Results depend on a wide range of factors and dynamics specific to the studies and their methods. For example, raptor pole use is likely to be most effective when prey populations are high (Macher 2017). The frequency and distribution of poles, along with species-specific preferences, will greatly influence usage rates of the poles and predation of prairie dogs. It is most likely that pole usage will not reach a rate where prairie dog populations actually decline but instead affects behavior. Continued raptor presence/pole use is needed to sustain the behavioral effects on prairie dog colonies. These factors can be difficult to control, making measurement of the effectiveness of raptor pole use much more difficult than other direct methods like shooting or poisoning. The landscape context (*i.e.*, vegetation height and visibility) will also impact how easily raptors can spot prey and whether the area requires pole installation.

Monitoring methods to inform future research

Several effective methodologies used in previous studies can inform future research on the interactions between raptor populations and prairie dog colonies. These methods, drawn from both experimental and observational studies, offer a foundational approach for designing future investigations.

One widely utilized method involves the use of **trail and wildlife cameras**, particularly motion-activated units installed on or near artificial raptor perches in fragmented and open landscapes (**Figure 3.4**). Studies by Kross et al. (2024) and Beltramo & Goudet (2025) have demonstrated the effectiveness of this technique for documenting raptor presence, behavior, and perch usage. These cameras provide continuous, non-invasive monitoring, capturing both images and video footage. Strategic placement on central perches allows for species-specific behavioral tracking and identification. However, successful long-term monitoring of perches and cameras requires regular maintenance, including structural modifications over time due to weathering and damage, battery checks, memory card replacements, and camera realignment on a weekly or monthly basis.

Figure 3.4. Setting and dimension of perches (on a fencepost), details of camera position, and camera clamped on wooden support. (*From* Beltramo & Goudet, 2025)

Accounting for temporal scale is another crucial factor underlined in many of the studies mentioned in this review. Kross et al. (2024) emphasized the importance of monitoring both before and after perch installation, ideally over full seasonal cycles and extending several years (3–5 years post-installation) to track meaningful changes in both raptor and prairie dog populations. While raptor activity can increase within days of perch placement, long-term data is essential to detect sustained usage and predation patterns. Additional techniques, such as pellet collection and visual surveys of predation events, have also been employed to assess raptor diet and impact on prey species.

Beltramo & Goudet (2025) contributed to the limited body of research on raptor behavior in human-modified landscapes by studying artificial perches equipped with camera traps over a two-year period. Their findings showed that perch usage varied across time and by species. Although their study only used two camera traps, it highlighted the potential for these tools to reveal daily and seasonal patterns in raptor activity. Future research would benefit from increased camera coverage and the infrastructure to manage and analyze large volumes of imagery, potentially linking perch usage data to variables such as prey availability, weather conditions, and interspecies interactions.

Complementary methods for monitoring prairie dog behavior and population dynamics include behavioral sampling (e.g., surface activity observations), burrow counts, and GIS-based colony mapping. These techniques help track colony structure, movement, and overall abundance. For example, Salas *et al.* (2024) used a multi-year historical dataset and roadside surveys across the Great Plains to analyze co-occurrence patterns between wintering raptors and prairie dogs. Their modeling incorporated variables such as climate, latitude, and habitat type, offering a robust framework for spatial analysis in future studies.

Other notable contributions include Cook *et al*. (2003), who used aerial and ground surveys combined with GIS mapping to explore how prairie dog presence influenced ferruginous hawk nesting in New Mexico, and Berry *et al.* (1998), who conducted multi-season point counts across 34 plots in Boulder, Colorado, to assess how urbanization and habitat composition affect raptor abundance. These studies underscore the value of integrating landscape-scale surveys with species-specific monitoring to understand the ecological dynamics at play.

In conclusion, future research should adopt a multi-method approach, combining camera traps, spatial analysis, behavioral observation, and long-term monitoring, to build a more comprehensive understanding of raptor-perch usage and its ecological implications that is representative of all collaborators' needs. Inclusion of seasonal and daily variation, prey population dynamics, and the influence of human-altered environments is key for improving understanding of these complex ecological dynamics. Developing hypotheses that directly study predation behavior, seasonality and environmental factors will further advance this field of ecology and help clarify the complex relationship between raptors and prairie dogs.

Conclusion

Our compiled research has immediate practical relevance for pest management, ecosystem conservation, and multi-species management in these contexts. By synthesizing information on raptor behavior, prairie dog ecology, and land management practices, this review underscores the potential for artificial raptor poles to serve as a practical and ecologically informed tool for biological prairie dog control in Colorado's grassland ecosystems. Ultimately, we aim to encourage future collaborative initiatives in research that apply community-based conservation strategies and solutions to sustain these essential ecosystems, species, and landscapes.

Artificial raptor poles can be an eco-friendly, cost-effective, and sustainable tool for solving the controversial issues associated with prairie dogs in shortgrass ecosystems. This can reduce the negative impacts of poison and shooting controls, which can cause trophic contamination with poison and lead traveling through the food web and killing raptors. Establishing raptor populations in the future can be a long-term, self-sustaining biological control that requires little maintenance for landowners and conservationists (Bontzorlos, 2024). Raptor poles may create an integrated and ecologically resilient management strategy for the future (Ronen *et al.,* 2024). This strategy aligns conservation goals with agricultural productivity and will hopefully be an effective leveraging of natural processes within the environment.

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4 MANAGEMENT METHODS

ECOLOGICAL & ECONOMIC IMPLICATIONS OF MANAGEMENT METHODS

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Large-scale grassland ecosystems, whether in the form of conserved lands, conservation easements, or privately owned land, provide critical ecological and economic services for a diverse group of species and can support livestock production (Whicker & Detling, 1988; Duchardt *et al*., 2025). Shortgrass prairie ecosystems cover a significant portion of Eastern Colorado. These landscapes increasingly face stress from urban expansion, habitat fragmentation, and increasing wildfire threats (Thomas Gifford & Barbier, 2025). Private landowners, who are responsible for a high percentage of conserved land in the U.S., are especially strained by decisions of balancing conservation needs with economic stability. Management of shortgrass prairies should respond to the unique spatial variance and needs of the landscape in order to maintain both ecological and economic health.

The black-tailed prairie dog (*Cynomys ludovicianus*) is essential to the shortgrass prairie ecosystem as it is a keystone species and an ecosystem engineer. Its burrowing and grazing activities enhance soil heterogeneity, promote water infiltration, and create habitat for a wide range of species, including burrowing owls and mountain plovers (Barth et al., 2014; Augustine & Baker, 2013). Still, prairie dogs are often seen as pests by landowners due to their potential competition with livestock (Witmer *et al*., 2000). The researched effect of prairie dog colonies on rangelands is contested; some research finds that cattle preferentially graze near colonies for the improved forage quality (Duchardt et al., 2025) while other research emphasize how older colonies increase bare ground and thus allow for noxious weed colonization (Whicker & Detling, 1988).

Federal support for prairie dog removal began in the early 1900s. In 1917, the Cooperative Campaigns for the control of ground squirrels, prairie dogs, and white-tailed jackrabbits began under the Department of Agriculture and over 26 million ha of habitats were poisoned between then and 1920 (Barko, 1997). Large scale poisoning and fumigation management projects were economically incentivized and initiated through the late 1900s, but have since tapered off in use following an approximately 90% decline in prairie dog population and an associated decline in the now endangered black footed ferret (Buehler et al., 2025). Still, prairie dogs can be legally exterminated by landowners in the state of Colorado as they are labelled a nuisance species, though most education on the matter encourages coexistence. In Colorado public lands, prairie dogs are classified and managed by Colorado Parks and Wildlife (CPW) through Title 33 in the Colorado Revised Statutes and the Parks and Wildlife Commission Regulations and by the Colorado Department of Agriculture under Title 35 (Living with Prairie Dogs | Colorado Parks and Wildlife, 2024).

Prairie dog management strategies historically enacted by both private landowners and landscape stewards (federal and national authorities) have variable efficacy and ecological and economic costs. To synthesize these impacts, after a literature review of primarily peer-reviewed articles, we compiled information on prairie dog management techniques and their relative costs and cascading ecological impacts. We summarized the cost, labor, time, and other considerations associated with each management strategy (**Table 4.1**). We have also evaluated the ecological importance of maintaining prairie dogs within a landscape and discuss how an Integrated Pest Management (IPM) framework can be applied for more comprehensive management strategies.

Non-Lethal Management Techniques

Capture and Release

Live-trapping is a popular method within urban and suburban areas where communities and regulations advise against lethal methods (Witmer *et al*., 2000). Live trapping is accessible to private landowners because they are legally allowed to exterminate at their discretion in the state of Colorado (Living with Prairie Dogs | Colorado Parks and Wildlife, 2024). Common traps include single or double-door wire mesh traps, such as Tomahawk or Havahart® brand live traps. These traps are then wired open, and often baited with horse sweet-fed mix, peanut butter, or rolled oats (Truett *et al*., 2001). Turett *et al.* (2001) also noted that pre-baiting is more important than the bait itself. To pre-bait, traps are set up near the colony in a more distant location for several days before being moved next to the burrow holes. The mortality rate of this method is less than 1% (Witmer & Fagerstone, 2003). This method is very labor intensive and time consuming but can effectively capture up to 80-85% of a colony when implemented properly (Witmer & Fagerstone, 2003). If the colony has plague and fleas, the time and labor costs increase because it is required for humans to wear protective gear, such as long pants and shirts, gloves as well as dusting prairie dogs with insecticide (Living with Prairie Dogs | Colorado Parks and Wildlife, 2024). Insecticides, such as deltamethrin or permethrin, can kill fleas which can reduce transmission of fleas between humans and prairie dogs (Tripp *et al.,* 2023). The ecological benefit of this method is that it does not capture an entire colony, so the remaining prairie dogs can still provide ecosystem services.

Once captured, the prairie dogs can be transported to approved release sites. To transport humanely, prairie dogs should be kept cool, especially during summer months, and with the traps covered to reduce stress (Truett *et al.,* 2001). Release sites can be wildlife preserves, conservation lands, or targeted areas for prairie dog reintroduction. Colorado Parks and Wildlife requires a permit for relocation which includes a $40 fee (Living with Prairie Dogs | Colorado Parks and Wildlife, 2024). Relocation permits can be found online and applicants must have landowner permission. The release site must meet minimum habitat requirements, which considers size, vegetation, slope, and soil type to be able to support a prairie dog colony. Applicants are responsible for understanding existing zoning laws and, if the relocations are during March through mid-June, consider how pup populations can be supported and transported (Living with Prairie Dogs | Colorado Parks and Wildlife, 2024).

In the state of Colorado, landowners are required to have permission of the county to release prairie dogs into that county because release of prairie dogs can negatively impact development and livestock production. To seek approval from the county, one must acquire the approval from the county board of commissioners (Living with Prairie Dogs | Colorado Parks and Wildlife, 2024). Despite these limitations, successful live capture and release can support conservation efforts by maintaining the beneficial ecosystem services that prairie dogs provide.

Release guidelines to support colony success are important, because if not met, they could hurt a population and an ecosystem by losing a food source and habitat engineer within a landscape. Within the approved release area, a team must prepare starter burrows. Starter burrows are artificial holes dug 1-2 meters deep to encourage settlement and vegetation above 12 cm should be cut (Truett *et al.,* 2001). In some cases, food and water are provided for several days after release (Truett *et al.,* 2001). Colony success ranges from less than 30% up to 70% depending on preparation, predator control, colony density, and plague (Truett *et al.,* 2001).

Vacuum method

Similar to live-trapping, the vacuum method offers capture and release but with faster capture. In 1991, Gay Balfour from Cortez, Colorado modified a sewer cleaning truck to create the vacuum truck for prairie dog removal (**Figure 4.1**; Truett *et al.,* 2001). In a vacuum truck method, a suction device with a 10-cm flexible hose is used to extract prairie dogs from their burrows (Truett *et al*., 2001). The equipment functions like an industrial vacuum, and creates enough suction to pull prairie dogs out of their burrows into a collection chamber. In this case, prairie dogs can be re-released into protected and approved areas. This method has a higher mortality rate (about 5%) because of internal trauma and broken bones due to impact forces (Witmer & Fagerstone, 2003 & Truett et al., 2001). This method is faster than live-trapping but does require special equipment and trained personnel. In summer, trained personnel can capture up to 100 prairie dogs a day (Truett *et al.*, 2001). It is not recommended to use this technique because of the mortality rate and potential trauma, but in management practices this is understood to be a quicker method if urban developments have time constraints (Truett *et al.,* 2001).

Figure 4.1. Vacuum truck (*Image from* Truett *et al.,* 2001)

Soapy Water

The soapy water method involves a mild soap solution being poured into burrows to flush prairie dogs to the surface where they can be trapped, typically by net (Truett *et al.,* 2001). This method is almost only used in emergency situations, such as when other methods have failed in urban areas. This is because it is unsuitable to have a high water consumption in remote areas (Truett *et al*., 2001). Adding a biologically safe soap to water reduces the surface tension of the water, allowing for the prairie dogs to have pockets of air. This allows for prairie dogs to be dislodged without suffocation.

The success of this method depends on soil type. For example, clay-rich soils, or more compact soils can retain the water longer which can increase the effectiveness of this method. In sandy soil, it would take more water to effectively use this method, which would increase the cost because of the need for more water. Water availability is an important consideration for this method, especially within Colorado, because of the drought conditions and the cost of water.

When the prairie dogs are captured with the soapy water method, proper care before transportation is important for their health and safety. Prairie dogs should be dried and allowed recovery time because this process is stressful (Truett *et al.,* 2001). This method is considered more humane than the vacuum method, but is impractical for large colonies due to its water demands (Truett *et al.,* 2001). It is also labor intensive, time consuming, and can cause habitat disturbance. Prairie dogs are habitat engineers; the burrows they create are essential to other species so, this disturbance would affect nontarget species residing in these burrows. This method is considered effective, but has limited efficiency and is more suitable for small colonies in urban areas and in cases of an emergency response (Witmer & Fagerstone, 2003 & Truett *et al.,* 2001). The soapy water method has limited research on mortality and efficiency rates, indicating that future research should be done to understand its full ecological effects.

Fencing (sight-line control)

Fencing is a method which is based on the idea that blocking sight lines for prairie dogs will both increase predation in an area and discourage colonization of an area due to prairie dogs preferentially building towns where sightlines are clear (Avila-Flores *et al.,* 2010). This method is controversial due to its questionable efficacy. Studies have shown that impeding sight lines through fencing does not have significant effects on prairie dog populations (Foster-McDonald *et al*., 2006). It also has a relatively large labor and materials cost due to the nature of setting up fences which would be able to resist cattle. These fences could also make crossing landscapes more difficult, as the bottom three feet must be opaque and therefore wouldn't allow passage under the fence.

Strategic Planting (sight-line control)

Strategic planting faces the same challenge of questionable efficacy as blocking sightlines using fencing (Foster-McDonald *et al.,* 2006). Planting could be a more efficient option than fencing if blocking sightlines is the desired option, as it can increase winter forage quality if the plants are chosen carefully. Plants such as mountain whitestem rubber rabbitbrush, basin whitestem rubber rabbitbrush, and fourwing saltbrush are good options for woodier species that can resist prairie dog clipping, as well as serve as high quality forage for cattle in winter months (Shoop *et al*. 1985). Unpalatable shrubs such as big sagebrush can be more effective for this sort of treatment, but have the drawback of reducing forage immediately under where they grow (Owens *et al*., 1991). They do, however, provide other important ecosystem services such as providing shade for cattle.

Lethal Methods of Management

Fumigation

Fumigation and poisoning management methods are less prevalent today compared to historic usage. These techniques require preliminary environmental analysis and often require professional application to minimize negative ecological effects. This initial process of sourcing labor and application of fumigants is time consuming, but the fumigation process itself only takes a few minutes (Boren, 2003). Common fumigation agents include aluminum phosphide, gas cartridges, or acrolein.

Aluminum phosphide is a restricted use compound that can be applied as a burrow fumigant only by certified pesticide applicators due to its high toxicity, reactivity, and flammability. It reacts with moisture in burrows to release phosphine gas, which is a non-persistent, non-mobile chemical (Boren, 2003). Because release of this compound is dependent on soil moisture, porosity, and ambient temperatures, efficacy is variable depending on location, but is usually 85 - 95% (Witmer and Fagerstone, 2003). Acrolein is a restricted use compound that can only be applied by certified pesticide applicators due to its toxicity and flammability. Though efficacy is around 90% for ground squirrels, it is only about 53% effective for black-tailed prairie dogs (Witmer and Fagerstone, 2003). This compound is not persistent and is not expected to bioaccumulate through the landscape, but like all fumigation methods, has a high risk of exterminating nontarget species occupying burrows. Gas cartridges (made of sodium nitrate and charcoal) are used as burrow fumigants for small mammals including prairie dogs, producing carbon monoxide in the process of combustion. This product does not require application by certified pest applicators as this is not a restricted use compound. This product is between 35 - 65% effective. The nitrate is mobile and serves as a plant nutrient in soil and water. The charcoal is immobile and is slowly degraded by microorganisms in the soil, so persistence in the landscape is not of concern. As with aluminum phosphide, adequate soil moisture is necessary for high efficacy (Witmer and Fagerstone, 2003).

Fumigants are effective for some uses. The EPA uses an efficacy standard of 70% after treatment. An assessment of the efficacy of various fumigants to manage black-tailed prairie dogs was conducted by Hygnstrom et al. (1998) and Hygnstrom and VerCauteren (2000); all five of the fumigants tested reduced burrow activity by 95-98% (Witmer and Fagerstone, 2003). Thus, this methodology has limited capability in boundary control or population reduction – only population elimination – which reduces the ecosystem services to lands once occupied by these keystone species (Roemer and Forrest, 1996). Nontarget burrowing rodents, burrowing owls, reptiles, rabbits, raccoons, foxes, weasels, and skunks are all potentially affected by this primary poisoning. In addition to these high ecological concerns, fumigants cost approximately 5 to 10 times more per acre than poison-grain baits (Boren, 2003).

Poisoning

Applying zinc phosphide to food crop fields (typically oats) is another widely used method of control for black-tailed prairie dogs, again requiring application by certified pesticide applicators. This process is most effective when pre-baiting, or non-poisoned baits are placed in and around burrows prior to the application of poisoned baits, yielding an efficacy of between 70-80% (Hygnstrom, 1998). Thus, effective application is higher in time consumption and labor costs. The direct consumption of zinc phosphide baits (primary hazard to nontarget species) or indirect exposure by the consumption of animals that have consumed the zinc phosphide (secondary hazard to nontarget species) are potential ecological hazards associated with this method (Witmer and Fagerstone, 2003). Though zinc phosphide does not bioaccumulate, anticoagulant poisons do (Fisher, 2019). Because application of this method to the boundaries of a colony can be specified, this method may be more useful in reducing a colony population to manageable levels than a comparable fumigation technique (Roemer and Forrest, 1996). Still, treated areas may quickly become repopulated, requiring additional treatments every few years; this limits the economic viability of this method (Witmer and Fagerstone, 2003).

Recreational Shooting

Unlike fumigation and poisoning, recreational shooting of prairie dogs does not require approval by a state or county in Colorado. On public lands, recreational shooting is allowed by all individuals with a small game license and on private lands; landowners are allowed to shoot freely even without a game license (Living with Prairie Dogs | Colorado Parks and Wildlife, 2024). Thus, recreational shooting is a common management technique used by private landowners. Some literature on recreational shooting even boasts the economic profit available to private landowners who rent out their land for groups interested in gaining target practice (Witmer *et al*., 2000). This management technique has variable efficacy, but with lack of state or federal regulations limiting animal harvest, a single shooter may kill over 170 prairie dogs in one session (Pauli and Buskirk, 2007). The preference for this management technique by private landowners is largely due to the lower time commitment, fewer legal restrictions regulating the technique, and relatively lower associated costs. Some research recommends the use of periodic, intentional recreational shooting on the boundaries of prairie dog colonies; proper utilization of this technique may reduce colonies to manageable levels without completely depleting the population (Hoogland, 2013).

The use of expanding bullets can pollute carcasses with casing, which is especially relevant when considering the material ammunition is made of. Lead based ammunition is highly regulated within riparian zones and water fowl hunting, yet is proportionally less researched and regulated in land habitats (Pauli and Buskirk, 2007). Unlike traditional hunting, carcasses are typically not utilized for food or resources – instead left untouched on the landscape. Because of this, predators that may consume prairie dog carcasses are potentially exposed to bullet fragments. One research study found that 87% of prairie dogs shot with expanding bullets contained bullet fragments as compared to 7% of carcasses shot with non-expanding bullets (Pauli and Buskirk, 2007). Carcasses shot with expanding bullets contained a mean of 228 mg of the lead-containing bullet core and 74 mg of the copper-alloy jacket, whereas carcasses shot with non-expanding bullets averaged only 19.8 mg and 23.2 mg of the jacket (Pauli and Buskirk, 2007). On top of higher quantities of lead released, the use of expanding lead bullets yields smaller surface areas of lead exposed in the carcass – resulting in quicker absorption of lead in the system. The amount of lead in a single prairie dog carcass shot with an expanding bullet is potentially sufficient to prove fatal to scavengers or predators (Pauli and Buskirk, 2007).

Figure 4.2. Visual of lead (top) and non-lead (bottom) bullets shot through gelatin (U.S. Department of Interior). Lead bullets typically fragment extensively, scattering numerous toxic pieces, while non-lead (copper/brass) bullets usually retain their weight, mushroom (expand) but stay intact.

Regulations and public concerns emphasize the importance of using rodenticides in a manner that reduces nontarget species losses and bioaccumulation (Witmer *et al*., 2000). As ecosystem engineers, the presence of prairie dogs facilitates the presence and survival of other species. The use of fumigation and poisoning techniques have high ecological costs. These methods impact nontarget species directly and indirectly, therefore, thorough evaluations of the landscape should be conducted to perform a cost-benefit analysis of the pest management strategy (Reading *et al*. 2002).

Table 4.1. Table showing options of sightline and barrier IPM strategies, with relative time consumption, cost, efficacy, negatives, positives and suggestions for landscape incorporation.

	Management Method	Time Consumption	Relative Cost	Efficacy	Ecological Effects
Non-lethal	Bait & trap	High	Low	High ~80-85%	Supports conservation efforts by thinning population, not depleting (+)
	Vacuum truck	Low	High	High	Considered inhumane (–)
	Soapy water	High	High	Low	Can destroy burrows for other species (–)
	Strategic planting	High	Variable	Variable	Provides shade, diverse forage types, and increases drought resilience (+) May reduce forage (–)
	Fencing	High	High	Low	Targeted protection of sensitive areas; reversible (+) Altered plant community composition; can impede movement of other non-target wildlife species (–)
Lethal	Fumigation	Labor-dependent	High; requires certified pesticide applicator (CPA)	30-95% depending on compound used	Complete clearance of burrows, leading to high mortality of nontarget species (–)
	Poisoning	High; labor-dependent	High; requires pre-baiting and CPA	~80%	Poisoning of non-target species; bioaccumulation/trophic cascades depending on chemical (–)
	Recreational shooting	Relatively low	Lower; dependent on bullet material	Variable; can reduce colony up to 65%	Bullet fragments & lead can enter ecosystem, depending on bullet type used (–)

Considerations for Management Practices

Looking at the effects of different management techniques at various scales is a vital step in making an informed decision about best management strategies. It's important to look at both the intended and unintended effects of these strategies. Methods that are high efficacy, high cost, might be best for acute instances where plague outbreak is a concern, whereas on long term, broad scales, low cost, passive methods that leverage ecological principles could be a better approach. Cascading ecological effects should also be considered for each management strategy, as well as the practice of removing prairie dogs from an ecosystem at large (Figure 4.3). Addressing prairie dog management at these disparate scales is crucial to understanding land use best practices.

Spatial variance and scale of a landscape impacts the proportional effect of prairie dogs, and thus the relative effects of prairie dog management. Larger proportions of prairie dogs on more volatile, smaller landscapes would be more sensitive to prairie dog management than the inverse. Local ordinances are a critical limiting factor in the management techniques that may be considered – especially lethal methods.

In line with integrated pest management approaches, prairie dog management should consider multiple techniques that both are effective for the landscape being managed and minimize negative environmental impacts. Further, management research emphasizes the need for community engagement between conservation experts and those directly impacted by these species. Case by case consulting may consider boundary management and relocation where possible, rather than complete elimination of a population to minimize negative nontarget effects. Balancing conservation and management priorities is essential for minimizing the cascading ecological effects from the removal of these keystone species, without compromising on ranchers' bottom line. Further research into the nuances of managing public versus private lands is needed for a more comprehensive understanding of shortgrass prairie ecosystem dynamics.

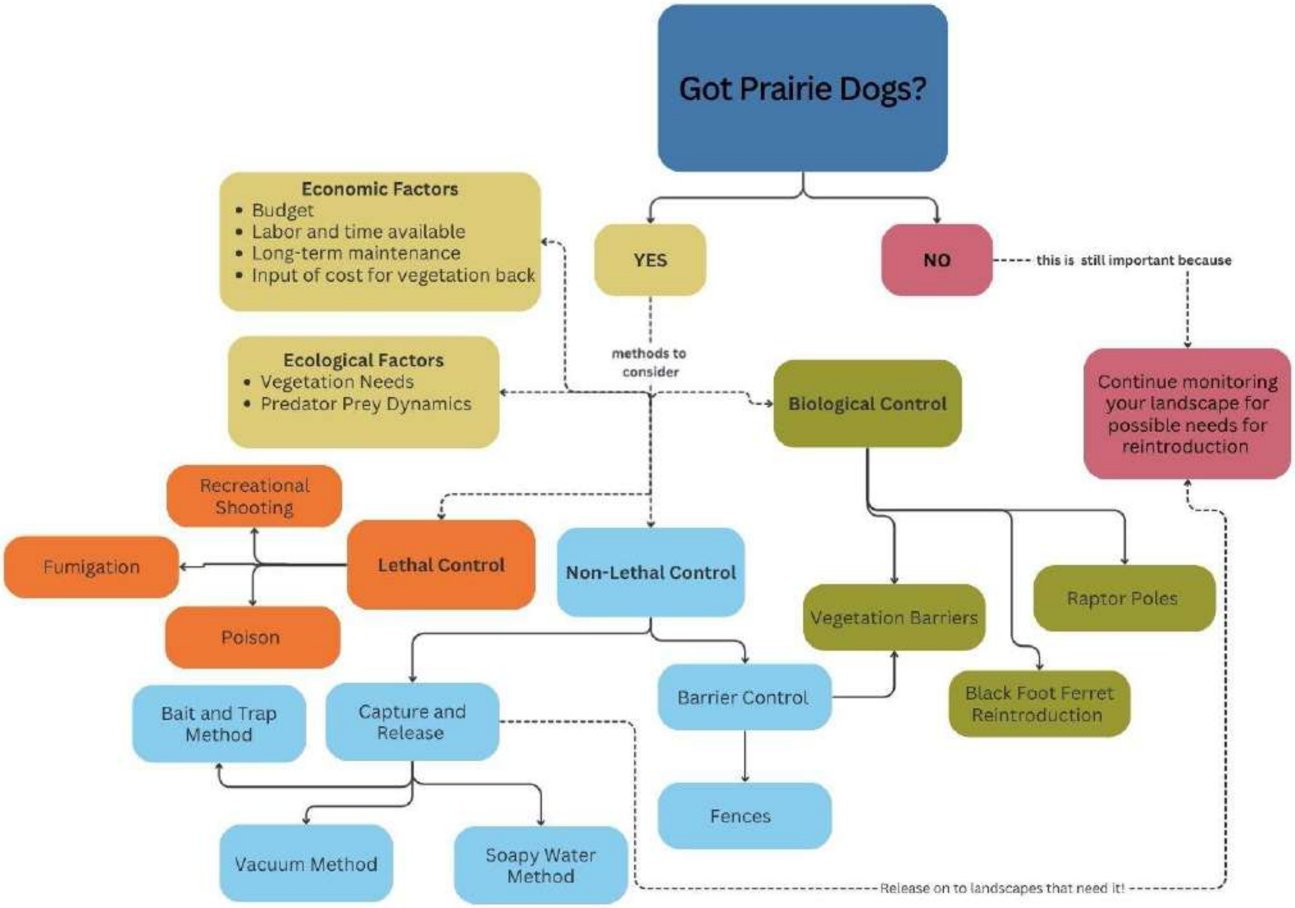

Figure 4.3. Flow chart showing prairie dog management methods, including ecological and economic considerations associated with each.

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