Evaluating UAS as a Tool for Improving Elk Population Counts in a Suburban Forested Area of North Central Colorado

by

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EXECUTIVE SUMMARY

Boulder County carries a unique and important responsibility in assisting Colorado Parks and Wildlife with management of resident elk. Overpopulation of the Red Hill and Rabbit Mountain herds was found to have detrimental impacts to sensitive open space, agricultural producers, and the public through ecosystem and crop damage and increased vehicle collisions. Key to managing an elk herd is accurately measuring the elk populations. This study sought to determine if utilizing an unoccupied aerial system (UAS), or drone, equipped with a zoom capable camera (not thermal) would be beneficial for performing elk population counts. Overall, the UAS system offered many benefits over traditional ground observation methods, with few drawbacks. Over the course of seven months, twenty-one flights were conducted at the same time as ground observations, with high quality images and videos of elk captured each time.

- The UAS consistently counted at least as many elk as the ground counts. In several cases, the UAS found many more elk, highlighting large errors in the ground counts.
- The UAS did not create a negative disturbance to elk observed; likely because of conservative UAS flying practices and these herds' acclimation with hikers, cyclists, and vehicle sounds.
- The drone's ability to efficiently move to a vantage point enabling visualization of entire herds was the primary benefit. Many times, elk were located where they could not be seen from the ground or only a part of the herd could be seen. The aerial view resolved this issue on many occasions.
- Not every situation required the use of the UAS, but having an optical zoom enabled UAS on hand during elk counts increased the efficiency and accuracy of the counts performed when challenging scenarios were encountered.
- Using a UAS adds a level of complexity to elk counting due to required training, airspace monitoring, wind and temperature limitations, and photo/video management and processing. The benefits, however, outweigh these additional considerations.

ABSTRACT

For decades, wildlife researchers have taken advantage of an aerial perspective for performing population counts because of challenges associated with ground observations. Due to advances in aviation technology and regulations, unoccupied aerial systems (UAS) have become increasingly available for wildlife population monitoring in addition to manned aircraft, with success largely dependent on the species, their habitat, and UAS utilized. This study compares a currently accepted method of counting North American elk (ground/spotting scope counts) to a novel method (UAS) to evaluate if a commercial-off-the-shelf quadcopter (COTS) UAS equipped with zoom-capable RGB cameras would be an acceptable tool for counting elk in Boulder County, Colorado. In addition, this study explored the operational challenges of utilizing a COTS UAS, such as disturbance to the elk, weather, and regulatory limitations. The primary data collected for this study were numbers of elk coincidentally counted by ground and aerial methods. By calculating and analyzing the differences in count numbers between the two methods, we sought to reveal if counts numbers varied depending on the collection method. Twenty-one comparative observations were analyzed with herd sizes ranging from six to 181. On average, 28 more elk were found with the UAS than by the ground method with the differences ranging from zero to 129 elk. Significance was found in the linear relationship between the aerial count and ground count, indicating the results were not random ($p < .001$). In addition to the method of collection, insight into the effects of field condition factors and how they impact the counting method was also explored through a generalized linear model selection process. Herd size and instances where terrain blocked the view of the herd for the ground observer were found to be significant factors in the count differences. A content analysis was performed to further

evaluate the link between the conditional factors and the count differences. It was found that herd bunching and a level field of view for the ground observer were other sources of major variability in the coincident counts.

Additionally, the effects of the drone on elk behavior were analyzed and were found to be minimal, even when directly overhead. This general lack of response is likely a result of these herds' acclimation to human activity due to the suburban nature of the study area. Overall, the aerial perspective and agility of the UAS proved to be highly useful for obtaining high-quality images of elk, especially when the ground view was not ideal. This study has shown that a COTS UAS with zoom capability should be implemented as a standard tool for ongoing elk population counts in Boulder County, with use expanded to additional elk herds.

CHAPTER I: INTRODUCTION

Background

The advantages of an aerial perspective for wildlife surveying were realized in North America as far back as the 1940s when the Canadian Wildlife Service used aircraft for caribou surveys to help confront "the geographical magnitude" of the areas that caribou inhabit (Benson, 1963). More recently, unoccupied aerial systems (UAS) have been employed as a new tool for conducting surveys and researching animal species on every continent. In North America, elk (*Cervus canadensis/Cervus elaphus*) are a closely managed big game animal brought back from the brink of extinction due to overhunting (Toweill & Thomas, 2002). A hotly contested debate on the proper taxonomic name for North American elk exists. As a result, they will be referred to as North American elk or simply elk in this study (*What's in a Name: Cervus canadensis versus Cervus elaphus*, 2022).

Near Boulder, Colorado, the Rabbit Mountain and Red Hill elk herds are flourishing such that they have become a nuisance and require careful management to ensure that their habitat and neighbors do not suffer from an imbalance on the landscape. This has pushed local and state governments to intervene, requiring extensive efforts to obtain accurate elk population numbers. Currently, the targeted elk herds are counted from the ground using binoculars and spotting scopes. This in-situ method is affected by visibility bias, resulting in high variability in the number of animals counted. These numbers have a direct impact on the management strategy, and thus, there is a need for accurate population estimations (Boulder County Parks and Open Space, 2020, 2021). This study sought to determine if the utilization of a camera mounted on an unoccupied aerial system (UAS) would be an effective tool for performing elk herd counts in comparison to the current ground-based method. In addition to analyzing herd count data quantitatively, this study explores the operational benefits and challenges such as level of effort, disturbance to the animals, weather, regulatory limitations, and limitations of the commercial off-the-shelf (COTS) UAS.

Aerial Surveying with UAS

As components for small unoccupied aerial systems (UAS), or drones, have become smaller, cheaper, and more widely available, popularity in the use of consumer grade UAS has soared. (Canis, 2015). The term UAS and drone will be used interchangeably throughout this report. The enactment of FAA Title 14 Part 107 in 2016 established rules for the commercial operation of UAS, allowing for limited utilization of UAS without a need for special permissions or waivers, as was required before 2016. Industries and governments, including but not limited to construction, mining, energy, filmmaking, emergency response, and ecological conservation, have taken advantage of UAS and the new rules to complete tasks more efficiently.

Small unoccupied aerial systems (sUAS) typically comprise an aerial vehicle equipped with sensors and a ground control station. The FAA defines small aerial vehicles as aircraft weighing under 55lbs with typical form factors consisting of fixed-wing, copter, or vertical takeoff and landing (VTOL) fixed-wing rotor combinations (Small Unmanned Aircraft Systems (UAS) Regulations (Part 107) | Federal Aviation Administration, n.d.). The powerplants of sUAS range from electric motors powered by lithium-ion batteries or hydrogen fuel cells, to small internal combustion engines. A basic set of sensors enabling remote flight include radio transmitters and receivers, global positioning system (GPS) antennas, inertial measurement units (IMU), and barometers. Ground control stations typically consist of a WIFI receiver that is used in conjunction with a smartphone or tablet that can show aircraft position, speed, heading, and battery life remaining, and in some cases, imagery from an onboard camera (Barnhart et al., 2016).

The intent of the flight largely determines the payload (additional sensor package carried by aircraft) and type of flight performed. The most common payload is a Red-Green-Blue (RGB) color camera. Other common sensor payloads include multispectral cameras, infrared thermal cameras, light detection and ranging (lidar) sensors, and air composition detectors (Barnhart et al., 2016). The level of integration and calibration required varies widely, with some systems being available commercially "off the shelf" (COTS) and others requiring extensive knowledge of payload systems integration. This study used a manufacturer integrated RGB camera on a DJI Mavic 3 Pro (Da Jiang Innovations, Shenzhen, China).

Each sensor provides different types of data driven by the mission focus. Red-Green-Blue cameras collect images and video and are commonly used in land surveying and wildlife monitoring, with data being collected manually or autonomously. Collecting images manually requires the operator to be able to see and control the real-time imagery from the UAS, using a smartphone, tablet, or integrated controller and device. Manually collected imagery is best suited to human-vision analysis or, in some cases, artifact identification using computer-assisted algorithmic detection. An automated survey is best for collecting imagery that will be merged into data products such as an orthomosaic or digital elevation model. An orthomosaic is a large, high-resolution image that is comprised of many (hundreds to thousands) of photos that are "stitched" together based on location and overlapping imagery features (Frazier & Singh, 2021). This study focused on manually collected and reviewed imagery.

Small UAS Regulations, Limitations, and Precautions

Small UAS operations are regulated by Ch 14 CFR Part 107. These rules outline how and where UAS can be operated within the National Airspace System (NAS). While Part 107 outlines where UAS can operate once airborne, private and public landowners can allow or disallow a UAS from taking off or landing on their land. No airspace permission was required for this study due to the class G airspace designation in the area. However, permission from the partnering organization, Boulder County, Colorado, was granted to perform operations on County land. Other regulations pertinent to this study were the requirement for the UAS to remain under 400 feet altitude above ground level (AGL) and to operate the UAS within visual sight (VLOS) of the operator. In addition to the regulations, flights were often limited by the battery life of the aircraft, which could not exceed 28 minutes per flight. Weather conditions also played a role, with wind and temperature limitations also occurring. The author was the primary UAS operator and is a certificated Remote Pilot in accordance with Part 107. To increase situational awareness, a visual observer (VO) was used where possible to assist the operator with airspace traffic and raptor monitoring.

Elk in Colorado and Boulder County

In the United States, wildlife is considered a public resource that provides many benefits to its citizens through engagement with food gathering and by providing economic benefits to local and national economies. The North American Model of Conservation establishes a framework that entrusts states to manage wildlife within their borders such that management decisions are based on science to ensure healthy populations of animals are maintained in an effort to satisfy the many stakeholders of wildlife conservation (Geist & Mahoney, 2019). Among the wildlife that are closely managed in North America are elk.

Before the enactment of hunting laws and because of the development of western Colorado from expanding agriculture and mining in the late 19th century, elk populations were reduced to an estimated 500 to 1,000 animals across the state in 1910 (Toweill & Thomas, 2002). Recognizing the need for protection and management of natural resources during this period, the State of Colorado created the Department of Forestry, Game, and Fish in 1897 (Young, 2021). Between 1912 and 1928, three-hundred fifty elk were reintroduced to Colorado from Yellowstone National Park. In 2020, CPW's Elk-Post Hunt Population Estimate found293,000 free-ranging elk in the state (Toweill & Thomas, 2002; Young, 2021). With nearly 300,000 elk, Colorado has the largest population of North American elk in the world. In addition to the ecological balance that elk provide, licenses for elk generate revenue for the State of Colorado, with the animals attracting tourists from across the world for hunting and wildlife viewing (Rocky Mountain Elk, n.d.). As a result, elk are an invaluable resource that requires careful management in today's continually evolving landscape.

Boulder County, Colorado, is located on the east side of the Central Rocky Mountains, approximately 25 miles northwest of Denver. Boulder County encompasses 742 square miles of rolling hills and agricultural land in its eastern half. It extends through alpine and subalpine wilderness on the west, with elevations ranging from approximately 5,000 ft to 14,000 ft above sea level. In the lower foothills, intermixed between the numerous population centers (Boulder County 2019 population: 326,000) are the Ron Stewart Preserve at Rabbit Mountain and Heil Valley Ranch Open Space; lands owned and managed by Boulder County Parks and Open Space

("About Boulder County," n.d.). In 2007 and 2008, the Ron Stewart Preserve at Rabbit Mountain and the Red Hill area within Heil Valley Ranch were found to "harbor the highest concentration of globally rare biodiversity elements." The elements include foothills natural communities, mountain mahogany shrublands, Piedmont grasslands, and shale outcrops hosting many bird species (Boulder County Parks and Open Space, 2021, p. 6).

Historical distribution of elk from coast to coast and from northern Canada and possibly to northern Mexico shows that elk are adaptable to various landscapes and climates (Toweill & Thomas, 2002). In Colorado, elk typically live in forested and alpine environments at high elevations in the summer and migrate to lower-elevation winter ranges when snow covers most food sources. In spring, elk migrate slowly back towards their summer ranges, following snow melt and vegetative green-up. In recent years, the St. Vrain elk herd has grown quickly and has expanded to become two distinct sub-herds: Rabbit Mountain and Red Hill. The landscape at Rabbit Mountain and Red Hill offers protection in the ponderosa forests and ample access to food from nearby agricultural fields. As a result of this transition zone providing all an elk's needs, including no hunting pressure, the elk stopped migrating to higher elevations during summer, and the resident (year-round) population increased dramatically. From 2003 to 2017, the elk population at Rabbit Mountain increased from approximately 25 to 350 elk, as seen in *Figure 1* (Boulder County Parks and Open Space, 2021). The Red Hill sub-herd was found to increase sharply from 2018 to 2019 by doubling to over 100 summer-range animals, indicating substantial calf survival and lack of winter to summer range migration (*Figure 2*). Boulder County concluded that the availability of resources from irrigated agricultural land, the lack of pressure from hunting, and the human presence on many parcels in the area created a comfortable environment for the elk to thrive. Toweill and Thomas (2002) confirm that when resources are not limited and when limiting factors such as predation and hunting are minimal, populations will grow exponentially.

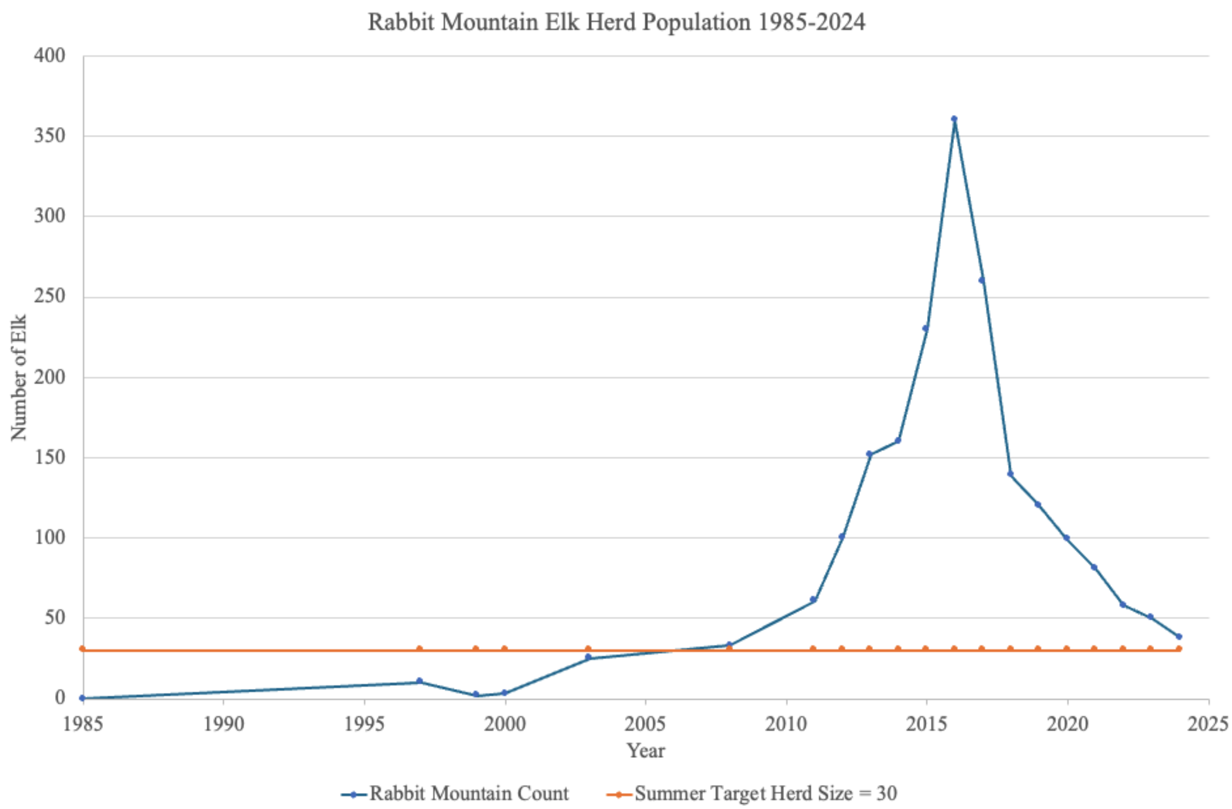

Figure 1: Rabbit Mountain Elk Population Data (Source: BCPOS, 2024)

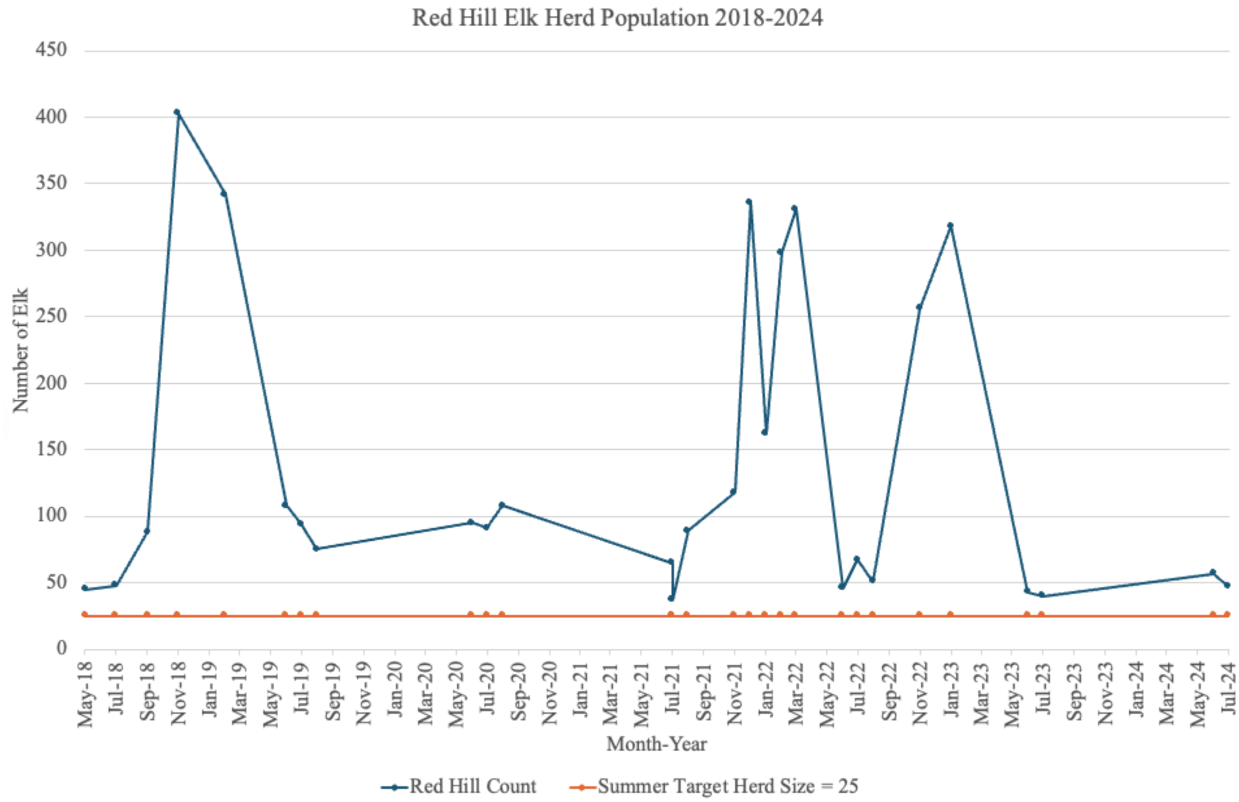

Figure 2: Red Hill Elk Population Data (Source: BCPOS, 2024)

Elk Conflict and Management in Boulder County

As the Rabbit Mountain and Red Hill sub-herds quickly grew, Boulder County and CPW witnessed increasing habitat degradation and elk-human conflicts. Boulder County monitored vegetation at the Ron Stewart Preserve at Rabbit Mountain and around Red Hill and found extensive damage to native plants and increased non-native vegetation (weeds) cover in high elk-use areas (Boulder County Parks and Open Space, 2021). The elevated elk populations and heavy traffic on US Highway 36 between Lyons and Boulder were found to increase elk-vehicle collisions despite, the implementation of various mitigation strategies. Additionally, there was increase in elk/vehicle collisions on US-66 (Boulder County Parks and Open Space, 2020). In addition to habitat and vehicle damage, CPW and BCPOS have spent considerable time and resources addressing crop and agricultural infrastructure damage, including paying crop damage claims. CPW and BCPOS have attempted to haze animals via various techniques, although animals were found to return shortly after hazing.

As a result of the increasing habitat and human conflict due to resident elk population increases for the Rabbit Mountain and Red Hill sub-herds, Boulder County and CPW evaluated various management strategies and found tightly controlled public hunting to be the most suitable form of management (Boulder County Parks and Open Space, 2020, 2021). In implementing the program, BCPOS and CPW determined the appropriate resident elk populations should be 70 elk in the winter and 30 elk in the summer for Rabbit Mountain, and 25 elk in the summer for Red Hill. Since initiating the public hunting program at Rabbit Mountain in 2017, the population has been reduced from over 350 animals to 81 during the 2021-2022 counts. The Red Hill hunting program began in 2020 and has shown a slight reduction in the summer herd. With the Rabbit Mountain herd nearing its target population, there is an increasing need for more accurate counts (Boulder County Parks and Open Space, 2022). As the elk population numbers are being reduced, increased accuracy will be even more important as small changes in adult survival can dramatically affect the population's rate of increase (Nelson & Peek, 1982).

Rabbit Mountain and Red Hill Herd Population Surveying

Aerial and ground surveying utilizing mark-recapture and sightability modeling are among the most established methods for performing elk population surveys (Bender et al., 2003; McCorquodale et al., 2013; Samuel et al., 1987; Toweill & Thomas, 2002; Unsworth et al., 1990). Marking elk typically involves capturing and immobilizing specific animals, performed through helicopter net-gunning, clover traps, or drive netting to attach a GPS collar around the neck (Beasom et al., 1980; Colorado Parks and Wildlife, 2021). Recapture is usually performed remotely by spotting the animals later, either by fixed-wing aircraft or helicopter, or using field glasses (binoculars and spotting scopes). Capturing and collaring elk is heavily resource intensive, requiring extensive human resources in terms of labor, training, safety, and highly specialized equipment. In addition to burdens on time and finances, safety issues are a concern for both humans and animals. A study by Sasse et al. (2003) found that flying at low altitudes is the leading cause of death for those in the wildlife profession. Likewise, capturing ungulates using helicopter net-gunning can lead to post-release injury and death of the animals (Jacques et al., 2009). Boulder County and CPW previously relied on collared elk to help locate and track elk, but safety and animal well-being concerns have influenced their decision to limit funding for capturing and collaring elk in the Red Hill and Rabbit Mountain sub-herds. As a result, only targeted ground counts using binoculars and spotting scopes have been used in recent years (J. DeCoste, personal communication, November 23, 2021).

Boulder County and CPW currently employ a herd adjustment model with herd populations generated from raw count data collected by trained individuals on the ground. Typically, counts are performed once a month from August to May. On a survey day, a group of surveyors disperse throughout the survey area by driving or hiking to areas where elk are usually seen. Once elk are spotted, individuals will move into the best positions possible to count the animals through binoculars or spotting scopes, with distances ranging from a few hundred meters to multiple kilometers. A total herd count and, if possible, a herd composition count (makeup of cows, calves, bulls) is performed. Multiple counters will obtain counts from different positions. Far distances, moving animals, grouped animals, and pointing optics directly into the sun have been noted as challenges for these ground observations.

Visibility Bias and Sightability Modeling

As discussed above, a host of factors has dictated that ground counts be utilized as the primary count collection method, although it may not be the most accurate method due to issues of visibility bias (animals missed during visual search). Samuel and Pollock (1981) state for ground surveys, there can be difficulty in observing all animals and that missing animals during ground counts can result in underestimations of population when using ground observations as a basis for a sightability function (probability of detection) (Caughley, 1974). Bender et al. (2003) compared count data collected via ground and helicopter and found differences between the two methods for elk and deer population metrics. They noted that helicopter data provide more consistent annual results over ground counts. Samuel et al. (1987) also discuss the advantages of aerial surveys over ground or fixed-wing methods and note that difficulties with terrain, cover, weather, and lighting problems experienced by ground observers can be reduced with an aerial perspective. These considerations, including the advancement of UAS technologies in recent years, have influenced the desire for wildlife management organizations to continue to exploit aerial advantages while circumventing issues of safety and cost associated with fixed-wing and helicopter surveys by exploring the use of UAS for elk population counts.

Key to evaluating new count data sources is understanding the factors contributing to sightability and visibility bias (Caughley, 1974; Unsworth et al., 1990). Sightability modeling refers to adjusting numbers generated by visually counting animals to account for animals not seen at the time of observation due to visibility bias (Samuel et al., 1987). Sightability modeling and visibility bias apply to counting animals via spotting scope, binoculars, fixed-wing aircraft, helicopters, and now UAS, with factors of visibility bias affecting the results of each method differently. It has been found that the probability of detecting animals depends on body size, group size, observer fatigue and experience, search speed, habitat, snow cover, and more (Toweill & Thomas, 2002). Two sightability studies from Samuel et al. (1987) and Unsworth et al. (1990) suggest performing surveys in winter when animals are in larger groups and more open terrain. Group size is also noted as impacting visibility bias (Samuel & Pollock, 1981).

Purpose of the Study

This study aimed to determine if a UAS is effective for performing elk population counts of the Red Hill and Rabbit Mountain elk herds. Effectiveness was primarily determined by statistically comparing the relative accuracy of counts using the UAS to ground counts and evaluating the usefulness of photo and video media for digital counting. In addition, factors affecting any discovered differences were assessed to determine if the UAS provides advantages over the ground count method. Assessing disturbance to the elk caused by the UAS was also investigated. Benefits, best practices, and potential pitfalls from previous studies that utilized UAS for performing wildlife surveys formed the basis for the research methodology. Information from earlier studies regarding visibility bias helped to narrow down factors that could lead to differences in counts. Still, this study did not seek to create a sightability model using these factors.

Research Questions

Does aerial imagery from a UAS provide an advantage over currently used ground count methodologies for performing population counts of elk in the wild?

- How do the numbers vary when comparing the number of elk counted in a herd using spotting scopes and binoculars versus aerial imagery? Is there a pattern observed when comparing multiple simultaneous counts?
- What external factors can count differences be attributed to?
- Does collecting aerial imagery allow for more precise discernibility between sex or age of animals observed compared to spotting methods?

Were there significant changes in elk behavior witnessed that could be attributed to drone noise?

Literature Review

UAS and Wildlife Surveying

Small unoccupied aerial systems have become increasingly popular as a tool for performing wildlife-related surveys, including coastal and landlocked birds, marine animals, large reptiles, and terrestrial mammals, including ungulates (Barasona et al., 2014; Brunton et al., 2020; Bushaw et al., 2019; Drever et al., 2015; Edwards et al., 2021; Linchant et al., 2018; McMahon, 2021; Preston et al., 2021). These tools are attractive for wildlife research because there is potential for increased efficiency in data collection, increased accuracy of acquired data, and the ability to cover difficult-to-access terrain (Bevan et al., 2018; Goebel et al., 2015; Hodgson et al., 2018). Because of their utility and novelty, many studies cover a wide range of animals and techniques, evaluating the efficacy of UAS for various species in varying landscapes (Elmore et al., 2023). This review focuses on studies that compared UAS-acquired abundance data to historical methods with an emphasis on true color imaging (RGB) of large land mammals, as they are most applicable to the study of elk. In addition to evaluating the efficacy, flight practices and recommendations from previous surveys are noted and discussed.

One of the first studies to directly compare UAS imagery data to independent ground counts is from Goebel et al. (2015), and evaluates the utility of sUAS for performing penguin and seal abundance surveys in Antarctica. The UAS imagery satisfactorily provided all necessary data. erial and ground count data showed no statistically significant differences but did show operational efficiencies in covering larger areas faster.

Brunton et al. (2020), utilized a commercial sUAS to successfully evaluate its efficacy for performing kangaroos counts. In addition to comparing aerial generated counts to ground observer counts their study focused on determining which factors most affected the successful detection of animals in orthorectified imagery created from RGB and thermal-infrared (TIR) imagery. It was found that vegetation type had the most effect, with open grasslands having the highest probability for detection, with lower sun angles and lower cloud cover also having a positive effect on detection rates. The comparisons of ground counts to ortho-imagery generated counts resulted in a 67 percent detection rate using the ground counts as truth. They also note that a manual review of the imagery should help to address the issue of false detections.

Mulero-Pazmany et al. (2014) utilized a fixed-wing UAS in Africa to determine its ability to detect rhinoceros and poachers in acquired RGB imagery. While they did not conduct a statistical analysis to determine the factors affecting detection, they found sufficient evidence that lower sun angles and lower flight altitude had a positive effect on successfully and manually identifying rhinoceros in the imagery.

Looking into the feasibility of using a small off-the-shelf quadcopter, Schroeder et al. (2020) investigated aerial imagery collected to perform counts of guanacos in open and arid rangeland. It was found that using the manufacturer integrated 20MP camera, guanacos could be counted with relative success at heights up to 180m AGL and aerial count numbers provided similar accuracy as coincidental ground counts.

These accounts generally inform the study, as COTS UAS are utilized to evaluate detection ability compared to ground counts while considering external factors such as flight height above ground, vegetation thickness, and time of day. Even though penguins, seals, kangaroos, rhinoceros, and guanacos are different animal species than the focus of this work, these establish a basis that the integrated RGB camera would be sufficient for identifying elk, which are larger than the other species except rhinoceros. These studies also suggest that imagery captured at the maximum flight altitude allowed (120 m) in open terrain should create sufficient data for counting. The comparison of aerial data to ground data varied in approach and accuracy for each study, indicating that a thorough investigation is necessary for each landscape and animal type being studied.

Previous Elk UAS Surveys

At the time of writing, there were only four documented instances of drones being used to survey elk. In 2014, the U.S. Geological Survey (USGS) used a 4-lb fixed-wing drone to capture video data of an elk herd known to be present in thick timber from radio collar locations (Cauvel, 2014). Email correspondence with a USGS contact indicated general unsuccess in this effort due to the thickness of vegetation, extreme terrain, and FAA limitations for maintaining VLOS (J. Adams, personal communication, April 4, 2022). In 2016, the Oregon Department of Fish and

Game also performed preliminary studies using COTS drones to capture aerial RGB and thermal video of elk in an open field. The information available includes sample videos of each data type where elk can be spotted in the imagery and did not appear to notice the drones. The FAA requirements to maintain a visual line of sight and to remain under 400 feet without waivers were noted as significant challenges to this initial study. The flights were performed in steep mountainous terrain, which could have exacerbated the regulatory challenges (ODFW, 2017).

In 2017, the Kentucky Department of Fish and Wildlife Resources (KDFWR) contracted for UAS imagery acquisition and processing to evaluate using UAS-mounted thermal sensors for surveying elk. This is the only elk-UAS study with specific data collection protocols and evaluation criteria. Flights were performed on two nights in March 2017 at two separate areas. KDFWR provided flight areas to the contractors broken into sampling grids 250 acres in size and determined based on the radio collar location data from the previous 27 days. Elk were known to be in the vicinity but were not observed visually from the ground at the time of flights by the UAS operators. Still images were captured to create thermal orthomosaics, although operational difficulties precluded this. Collecting images with similar ground resolutions proved to be a problem in areas with very steep terrain as height above ground was inconsistent. In addition, the operators had concerns with automated flight plans and terrain and obstacle avoidance and resorted to manual control for nadir images. As a result, the images did not have enough overlap for mosaicking. Video was collected at one of the sites, and an elk herd was recorded. Initially, the animals were in an open grass field but quickly moved to nearby timber in the video. It is suspected that the drone's noise startled the animals and caused them to seek cover. Overall, there was an 82 percent species-level identification rate, which KDFWR did not find sufficient.

The resolution of the imagery was not high enough to confidently identify the difference in ungulates (whitetail deer vs elk). It was certainly not high enough to determine sex and age class. KDWR determined that thermal UAS surveys would not be effective enough for widespread use based on the results of this initial study.

In 2018 and 2019, Graves et al. (2021) performed a study comparing satellite, UAS, and GPS-collar data for determining elk density metrics at the National Elk Refuge in northwest Wyoming. For the study's UAS portion, they performed 24 flights using a COTS drone over elk congregated in a winter feeding zone. Their approach utilized the drone in a targeted manner for mapping the herds not restricted by airspace. Two of the UAS flights coincided with ground counts, resulting in 1 percent and 12 percent differences, indicating that the UAS performed well compared to the accepted method. Sample pictures of their data, an overhead image from 150m above the elk, show clear delineations of elk, making it possible to perform an accurate count. They note that UAS could continue to be used successfully for assessing change in small spatial extents due to flight restrictions and drone battery limitations.

This KDFWR study echoes the challenges of the ODFG pilot project, where steep and rugged terrain created severe limitations on flight while staying within the FAA regulations. For the KDFWR study, only a single location was used for landing and launching for each overall survey area. Ground mobility and multiple options for launch and landing helped alleviate some of the regulatory burdens associated with maintaining a visual line of sight and remaining below 400 ft in my study. Also, the design of the KDFWR study, where locating and counting elk with solely the UAS was attempted, implied that UAS were to replace helicopter surveys, which would be difficult to do with current regulations in place.

The USGS, ODFW, and KDFWR studies did not find UAS to be completely effective for surveying elk. The design of this study most closely resembles that of Graves et al., in which the drone is not primarily used to find elk, yet is used to survey them after being located in commonly inhabited areas. Considering this, it was hypothesized that under certain conditions, a COTS UAS would be a useful tool for BCPOS to perform elk counts. In addition, it was predicted that land and launch locations could be strategically selected to reduce the impact of VLOS and the 400ft height requirement. Using thermal imagery is attractive; however, the low resolution of current cameras, the cost of thermal sensors, and additional operational considerations, such as flying at night, precluded the use of thermal imaging for this study. Using lessons learned from the previous elk-drone studies as well as investigations for other animal species, it was expected that a protocol could be developed such that a COTS UAS with an RGB camera could be a valuable tool specifically for the sub-herds that occupy Boulder County Open Space land.

Considerations from the Literature

Collecting aerial imagery to produce data where it is possible to identify individual elk and herd composition with high certainty is the primary driver of the survey parameters. The literature shows that lateral distance to the animals, the openness of vegetation, flight altitude, time of day, and lighting conditions will have the largest impacts on imagery quality. Lateral distance to animals, flight altitude, and lighting conditions are directly related to the camera's capabilities as these variables will impact image resolution, affecting a reviewer's ability to differentiate between individual animals, sex, and cow vs. calf. The closer the camera is to the animals, the more clearly the animals will be able to be differentiated. Time of day and lighting will also impact imagery and observation, where animals could be backlit and the camera sensor overwhelmed by direct sunlight. Proper camera positioning can help minimize the negative impacts of low-sun angle, but may not be possible at all times. Sun-angle could also aid in reviewing of the imagery as shadows produced by elk can help to highlight their presence (Toweill & Thomas, 2002). The openness of vegetation is expected to have the most significant impact on the accuracy of counts (Brunton et al., 2020; Samuel et al., 1987; Schroeder et al., 2020). Trees and shrubs could obscure animals and make it difficult to discern between age and sex. This also applies to observations made on the ground, although the UAS can change the angle of view more easily.

The anticipated advantages that the UAS provided over ground counts were related to its mobility, aerial perspective, and produced record in digital format. Ground observers would be restricted to areas with road and hiking access. A UAS can be launched from these same locations, but it can get closer to the animals and view them from above. It was expected that viewing the animals from above could reduce the effect that "bunching" of animals has on ground observation and can enable viewing of animals when terrain blocks the view of animals from the ground. In addition, if an observer is using binoculars or spotting scopes and facing the sun, it is extremely difficult to see anything. A UAS may be able to orbit around the object to gain a better perspective. By collecting images, the scene is frozen, and multiple instances can be collected so that the most beneficial image can be reviewed post-collection. Reviewing images and video after collection could also reduce the impacts of observer bias, including eye fatigue and the effects of the elements on the observer. Hodgson et al. (2018) discuss that the aerial advantage and digital recording of simulated seabird colonies were large factors when they determined that aerial data provided more accurate counts than traditional ground count data.

Elk Disturbance Limitations

While obtaining images at close enough distances to discern the sex and age of animals was desired, the level risk of disturbing the elk, such that a flee reaction could occur, was unknown. Although disturbing animals to “flush” them into open areas is considered an advantage of helicopter surveys (Samuel et al., 1987), acceptance of this technique is not necessary nor appropriate in all studies. Since the use of UAS for wildlife studies has increased, many stakeholders have been concerned with how UAS may disturb wildlife, and several studies have investigated this for a wide variety of species (Mulero-Pázmány et al., 2017). Hodgson and Koh (2016) recognized the lack of empirical data when publishing their article and suggested that when studying wildlife with UAS, extreme caution should initially be used and that flight practices be shared in detail so that subsequent studies can benefit from lessons learned.

A common theme between many recent studies of large terrestrial mammals indicates that vertical and horizontal distances from the animals are the most significant factors affecting a response, with closer distances causing increased response (Bennitt et al., 2019; Brunton et al., 2020; Schroeder et al., 2020). Bennitt et al. (2019) found that altitudes lower than 60m AGL and distances closer than 100m elicited a response in all animals studied. During a study of UAS for guanaco counts, Schroeder et al. (2020) found that herd size and horizontal aircraft speed elicited at least a vigilance response. In a study of domestic cattle, Abdulai et al. (2021) found that beef cattle did not respond to the UAS, even at close range (9 meters), and suggested this may be due to strong familiarization with humans. Lenzi et al., (2022) evaluated the response of feral horses and bison to a fixed wing drone at 120m overhead and found a change in behaviors due to the drone, but found no instances of escape behavior. The Kentucky Department of Fish and Game study hypothesized that the UAS caused the located elk to move into timber. However, the report does not indicate that any precautions were taken to avoid a flee response. These studies of large land mammals suggested that maximizing distances, minimizing flight speeds, and initially avoiding direct overflight of elk would be the most precautionary approach. In addition, there was hope that because the areas surrounding the Rabbit Mountain and Red Hill Open Space areas were populated with humans and vehicle traffic, the elk being studied in this area would be more tolerant of non-natural noises. Despite the risk of disturbing elk with a UAS, it is possible that this method causes less disturbance than approaching animals on foot (McMahon, Ditmer, Isaac, et al., 2021).

CHAPTER II: METHODOLOGY

Data Collection Methodology

The field campaign for this study occurred between October 2023 and May 2024. Overall, 21 coincidental ground and aerial count observations were analyzed. Of the total, 18 were of the Red Hill herd and three of the Rabbit Mountain herd. All observations were completed in Boulder County in habitats ranging from ponderosa-dominated foothills, prairie grassland, and agricultural fields covering approximately 39 square miles. Aerial photos of the study area are presented in *Figure 3 and Figure 4*. Elevations ranged from 5,060 ft to 6,353 ft above sea level. All observations were completed with Boulder County wildlife biology staff and under University of North Dakota IACUC Protocol #2210-0047. All flights were performed in accordance with Boulder County UAS permits and all FAA Part 107 regulations.

Figure 3: Representative aerial photo of the general study area. Looking east, ponderosa dominated foothills give way to developed agricultural and suburban mixed-use land in rolling terrain

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Figure 4: Representative aerial photo of the general study area. Looking south along the Front Range at the foothills and agricultural/grassland transition zone. Elk inhabit the spectrum of land shown, year round.

Elk Locating

To directly compare ground-derived counts with UAS-derived counts, a collection protocol was centered around coincident counts. The land and launch locations of the UAS were close to the ground observation point, and ground counts occurred during aerial media collection (during flight). This study sought to evaluate the tools used to derive raw counts. Therefore, the primary intent was not to use the UAS to discover elk but rather to assess their numbers once located (although discovery did inadvertently occur). Elk were located by driving around the study area and glassing (looking for animals through binoculars) for elk. This method proved successful for this specific study area due to the rolling topography and many roads in the study area. In addition, elk could typically be found in several “favored” locations. When elk could not be located from a vehicle turnout, short hikes into favored elk habitats would occasionally result in locating the elk.

Once elk were located, the team, consisting of a minimum of the author as the UAS operator and the BCPOS elk program coordinator as the ground observer, would move into a position to perform a ground count. This was performed in the same manner as a typical ground count, as if the UAS were not there, to replicate the standard procedure against which the UAS was being evaluated. This involved moving into a position providing the best view possible without much additional effort. In most cases, there was a suitable launch and land location for the UAS within tens of meters of the ground count location. On occasion the ground location and UAS launch location were not within meters of each other, but this was not considered an experimental discrepancy because the drone is highly mobile once airborne. The most significant distance between the ground observation point and the UAS launch point was approximately 800 m in flat open terrain, where visual contact was maintained between the ground counter and the UAS operator.

Ground Counting Protocol

Once elk were located and a suitable ground count position was found, the ground observer would perform the count using a Kona TSN-553 15X-45X tripod-mounted spotting scope. The counting procedure involved tallying elk while scanning the herd laterally. This was performed multiple times until a number was repeated confidently. A total herd count was performed, and if possible, a cow/calf/bull composition count was also performed.

Aerial Counting Protocol

UAS System

The aerial counting protocol consisted of performing UAS flights near located elk to gather photos and video of the targeted elk herd. A DJI Mavic 3 Pro (Da-Jiang Innovations, Shenzhen, China) was used for all data collection. This drone was selected due to its ease of use, compact size, powerful pre-integrated optics, and weather tolerability. The Mavic 3 Pro (M3P) is a commercial off-the-shelf (COTS) quadcopter system that weighs 2.1 lbs and is capable of sustaining 43 minutes of flight time in nominal conditions. The DJI RC controller was utilized and has an integrated touch screen, eliminating the need to use a phone or tablet to control the system. The four arms and propellers of the M3P fold up and remain attached in storage, allowing for easy carriage in a backpack. These features were helpful for rapid deployment in situations where necessary. This version of the M3P came with three pre-integrated cameras offering three optical zoom levels and up to 28x digital zoom: 1x 20MP Hasselblad 4/3 CMOS sensor (24mm equivalent), 3x medium telephoto 48 MP 1/1.3" CMOS sensor (70mm equivalent), 7x telephoto 12 MP 1/2" CMOS sensor (166mm equivalent). It is capable of flight in winds up to 26.8 mph and in temperatures ranging from 14° F to 104° F (https://www.dji.com/mavic-3-pro/specs).

UAS Flights

UAS flights were unique for each counting scenario due to location, terrain, herd positioning, weather, and other factors. Due to this, photo and video acquisition of elk groups were conducted in a manually targeted manner, not in an automated mapping mission mode. In the beginning stages of the data collection campaign, larger separation distances were practiced to gauge the level of response from the elk to the drone. A lack of response by the animals throughout the campaign made it reasonable to decrease the distances gradually.

Once in position after locating the elk, their distance from us was estimated using a mobile device mapping application, onX Hunt (onX Maps, Montana, USA). Initially, 300 m was selected as the minimum separation distance from the elk to the drone based on noise levels of the drone experienced during practice flights. After clearing the airspace, the drone was moved into a position within the appropriate separation distance, within the operator's visual line of sight, which provided the best angle from which to view the animals. Each scenario required a manual assessment of these requirements.

Depending on the complexity of the herd distribution and formation, flights ranged from five minutes for small groups in open terrain to 30 minutes for a large group spread throughout a vegetated hillslope. The main objective of the media acquisition was to capture the entirety of the group with a high enough image resolution to identify elk confidently in the digital counting phase. Ideally, animal age class and sex would be determinable, but this was not always possible. Specific media acquisition techniques for herd counting involved first observing the herd from a zoomed-out perspective to estimate the extent of the herd spread and to ensure all animals would be captured. Zoomed-out photos and videos were also recorded for setting and contextual data purposes. The videos and photos were captured at various zoom levels while panning laterally and vertically. Photos were captured with high overlap so that "photo-stitching" of the scene would be possible later. Generally, photos were taken at the base level of the camera (1x, 3x, or 7x) so that no digital distortion was introduced in the raw photo. Videos were zoomed (typically 3x to 14x) to capture an appropriate level of detail while also being zoomed out enough to keep track of where within the herd the focus was and to reduce the number of passes it would take to cover an entire herd. Slow and smooth manual panning speed (vertical and horizontal) was important for digital counting efficacy. The slow pan videos were performed to mimic an observation of the elk through binoculars. It was sometimes more advantageous to record a slow pan video instead of taking multiple overlapping photos. This occurred when the elk were in an area where vegetative cover could obscure elk, and motion would help identification or when there was movement within the herd. The manual acquisition was also simplified using slow planning rather than a “pan – stop – capture photo – pan” technique. Typically, the photo and video capture sequence was repeated from one or two UAS positions.

Elk-UAS Response Observations

Assessing elk response to the UAS was not the primary objective of this study. Still, it is necessary when the response from a specific wildlife population to a UAS is unknown. In addition, the repeated measurements provided an opportunity to gauge these herds’ tolerance to drones throughout various field conditions. The protocol for assessing elk behavior was straightforward: actions and behavior were observed and recorded before UAS launch, during, and after the flight. Action categories were Bedded, Grazing, Milling, Standing, Slow Transit, Grouping, and Moving. Alertness categories were non-vigilant, vigilant, and fleeing. These behavior categories were informed by previous research looking at mammal responses to drones (Bennitt et al., 2019; Lenzi et al., 2022; Schroeder et al., 2020). Expanding upon their methods, a combination of action and alertness observations is introduced, which provides higher granularity for elk status assessment. A change in an action or behavior could indicate decreasing tolerance, whereas no change in either could falsely indicate tolerance. For example, if the elk were bedded and acting vigilant before flight and then during flight the elk stood up, recording only vigilance for the before and during flight condition would indicate no change in behavior. However, by standing after being bedded, this action change would indicate a change in the degree of vigilance. Typically, individual elk exhibited various action and alertness behaviors, in which case multiple categories were recorded.

Recording elk behavior involved observing the elk groups through binoculars and the spotting scope for a few minutes before UAS launch. Then, with the ground observer viewing the elk, the UAS was launched and flown into the media collection positions. Two-way communication was maintained between the ground observer and UAS pilot to indicate if the elk responded negatively to the approaching UAS. If any indication of a negative response caused by the UAS was suspected, the UAS was immediately distanced, although this rarely occurred. Once the UAS was in position, behavior was also monitored via the UAS camera. It was also possible to review elk behavior post-flight from the recorded videos. Recorded elk behaviors for each mission are found in the results section.

Ancillary Factors Data Collection

Variability in the observation locations and environment was recorded so it would be possible to evaluate the effect of these factors on count differences found between ground and aerial measurements. The factors recorded are found in *Table 1*. These factors were selected based on previous ungulate sightability research because they could be reliably recorded with enough occurrence for analysis (McCorquodale et al., 2013; McMahon, Ditmer, Isaac, et al., 2021; Samuel et al., 1987). Factors such as snow cover and elk in shadows were not explicitly analyzed because the occurrence of these either partially existed in a single observation or only one or two occurrences existed and would not provide enough data for conclusive analysis. Time of year, temperature, and weather were not analyzed explicitly as herd size can be considered a covariate of these due to elk habits; in the colder months, larger elk groups tend to be found with herds dispersing into smaller groups as temperatures warm (Toweill & Thomas, 2002).

Table 1: Ancillary data factors with categories identified

Factors	Category
Herd Size	Very Small (1-9) Small (10-29) Medium (30-90) Large (90 +).
Ground View Obscuration	Yes, No
⊗ in Aerial-Ground Obs. Distance	meters
Terrain	Flat, Hilly, Steep
Vegetative Cover	Open, Semi-Open, Brushy, Treed, Mixed
Herd Formation	Tight, Spread, Mixed
Herd Action	Bedded, Standing, Mixed

Ground view obscuration occurred when elk were obscured from the ground viewer's point of view due to terrain. This was determined by comparing the elk viewed from the ground compared to what was seen by the UAS in the field. Because the ground view locations and UAS launch locations coincided, the UAS operator also had a view of the elk from the ground and could determine if some were not visible. Once the UAS was in position, it would become clear from the UAS camera view on the controller if the elk were obscured for the ground viewer. If any part of the herd was hidden from the ground observer due to terrain, then this count was considered to have ground view obscuration. An example of an observation with ground view obscuration is presented in *Figure 5*.

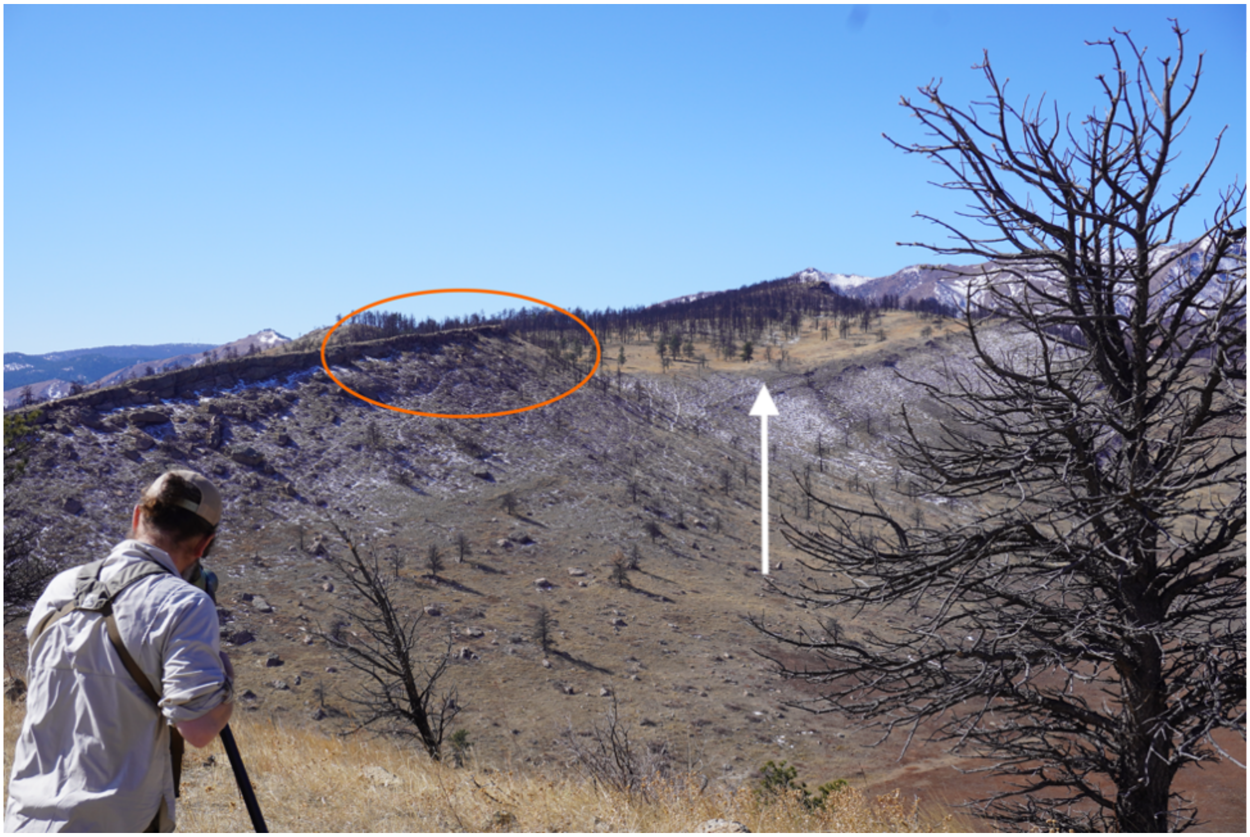

Figure 5: An example of an observation with Ground View Obscuration. Elk are hidden from the ground observer's view by a ridge, circled in orange. The ridge obscures approximately one-third of the meadow that the elk were in (white arrow pointing to meadow)

Terrain, vegetative cover, and herd formation were noted in the field and verified through the collected UAS media. Terrain refers to the steepness of the ground where the elk were when the observations were made. Categories were used instead of slope angles because often, a group occupied many slope angles, making it impossible to choose the appropriate number. Instead, the dominant level of flat, hilly, and steep was chosen. These categories provided a sufficient description of the range of terrain types within the study area. The vegetative cover was described as the open, semi-open, brushy, treed, and mixed cover. Open refers to land with no vegetation (dirt) to medium height grasses that would not obscure an animal. Semi-open cover indicates medium to tall grass areas with sparsely intermixed trees and/or bushes that could potentially hide animals. Brushy refers to areas with large bushes and brush dominating the primary elk location. These bushes and brush would produce obscuration if an elk were behind the brush. Treed refers to a forested area where trees dominate the scene, and only small pockets of ground can be seen. Mixed refers to areas where the elk are spread throughout a combination of the other categories such that one is not dominant. *Figure 6* shows representative terrain and cover types encountered.

Ground and UAS observation distances to elk varied throughout the study. Ground distances were determined by mapping the location of the elk (center of the group) and ground observer using the mobile mapping and GPS app onX. Locations of the elk and ground observation points were recorded in the field and verified after. The distance between the elk and ground observation points was measured using the digital measurement tool within the app, which measures the straight-line distance. Distances of the UAS to the elk were recorded post-flight by uploading the UAS flight logs to the web-based application AirData (California, United States). AirData deciphers the flight logs and visualizes pertinent information such as flight time, distances, battery levels, media capture events, and more. Media events are timestamped and geo-tagged, providing a precise location of the UAS when a photo or video is recorded. The coordinates for the media used in the aerial digital count were transferred to onX, and the distance measuring tool was used to measure the ground distance between the center of the elk group and the UAS. The height of the UAS was also logged, and the hypotenuse distance was calculated to find a UAS to elk distance.

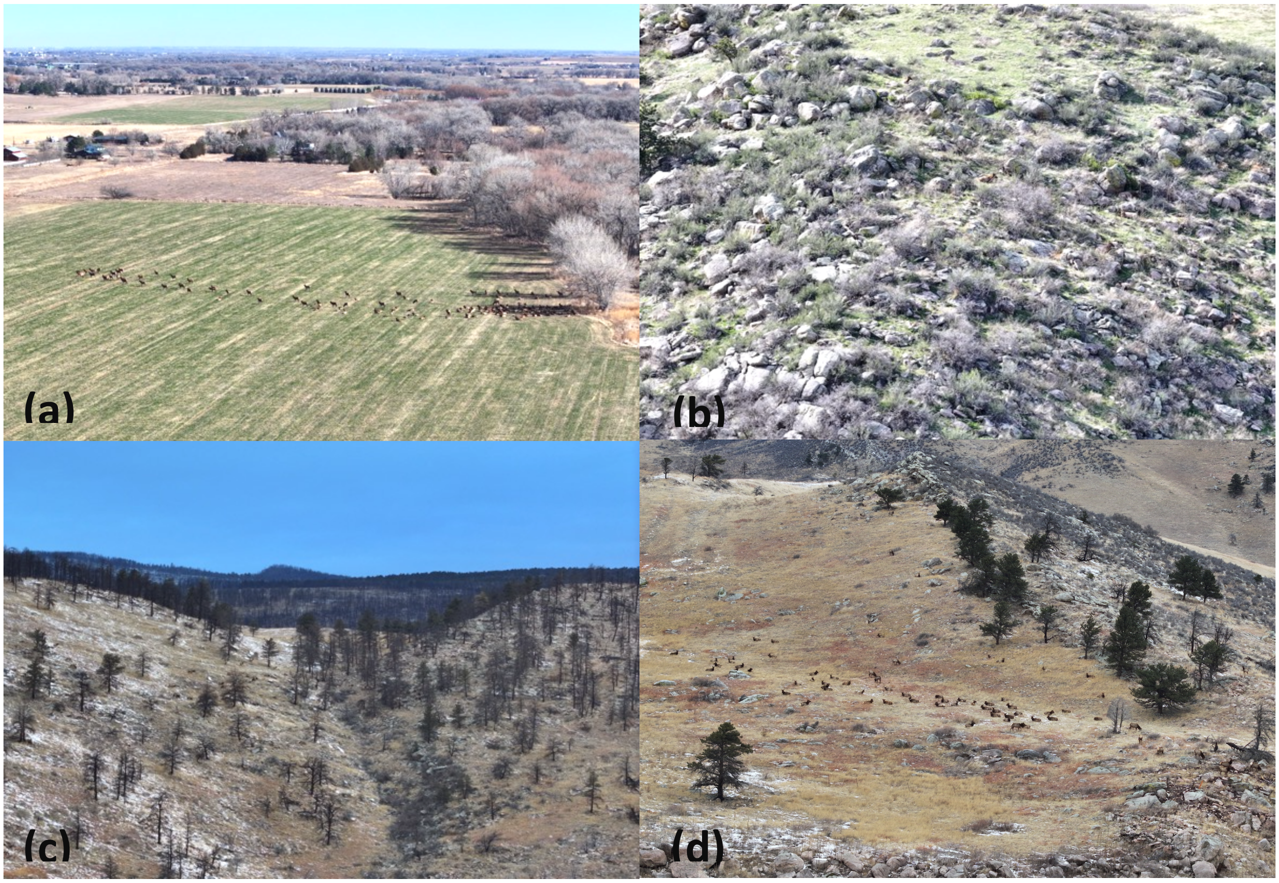

Figure 6: Example of terrain and cover where elk observations occurred: (a) flat open field (b) brush covered hilly slope (c) semi-open trees on steep slope (d) mix of open, treed, and brushy flat and hilly terrain.

UAS Media Processing

The first step in media processing was to review all photos and videos and identify media that provided the highest level of detail, contained the full extents of the herds, and facilitated digital counting to give the most accurate count number. The raw media was then transformed into counting products. These included single photos, merged photos, merged video still frames, and standalone videos.

Single photos of entire herd groups were preferred because they don't require a merging step, and there is no concern about elk moving between captures. Multiple overlapping photos were used to create a counting product in cases where semi-large herds were spread out but not moving, such that a single photo would not provide an adequate level of resolution to confidently discern individual elk. Photos were merged using Adobe Lightroom (Version 7.5, California, United States) and the “Photo Merge” tool. Each resultant merged photo was checked for distortion artifacts, but none were found.

On missions where the primary media collected was a slow pan video, as opposed to overlapping photos, a single image was created from video still frames. This method was used in cases where it was difficult to count the elk in the video itself due to the high zoom level and moving animals. The procedure to generate a video still frame counting product was to review segments of the video and to pause the video where elk movement was minimized and where there was sufficient overlap with the previous frame. This was performed in Adobe Premiere Pro (Version 24.6.1, California, United States). At the pause points, the “Export Frame” tool was used to save the frame as a photo. Once the entire video was parsed into frames, they were merged in Adobe Lightroom using the “Photo Merge” tool. Standalone videos used for the counting process did not undergo any additional processing.

Digital Counting Protocol

Counting within the generated count products was performed manually by the author and verified by trained Boulder County wildlife biology staff. This study's count refers to the total herd count without specifying sex or age (herd composition count). Counting for herd composition was explored, but a lack of consistency of high-resolution imagery combined with a herd composition ground count did not provide enough data for a full comparative analysis. In addition, while many digital animal counts have utilized automated programming called object-based image analysis for performing counts, this was beyond the scope of this study.

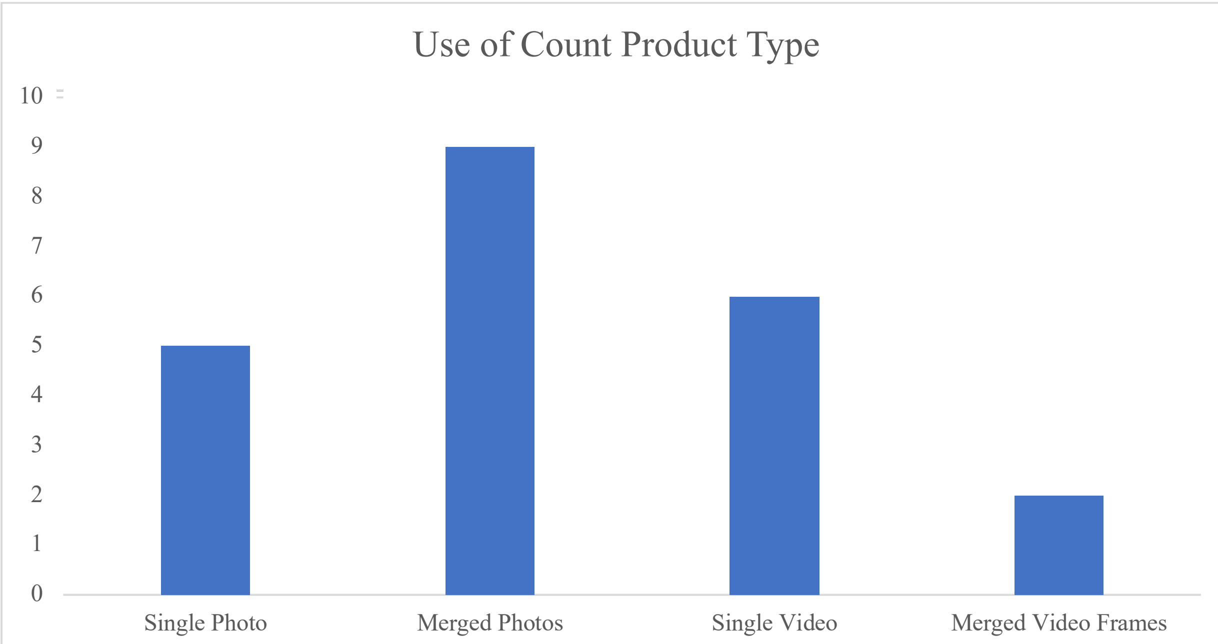

Figure 7: Distribution of count product type used for digital counts

The distribution of digital products utilized for final counts is presented in *Figure 7*. In most cases, video was used to verify photos (companion videos), but in some cases, video provided more robust information for counting. A quality companion video started zoomed out, then zoomed in and recorded a slow pan, providing overall scene context. Watching the video, it was useful to note movement in cover and behind trees, especially ear flicks. The preference for photos over video stems from being able to use "click-counting" software on "stationary" animals. While counting in the photos, it was useful to refer to the video to determine if any objects in question were elk, usually based on some movement or through a different perspective or zoom level.

Photos

Single photos, merged photos, and photos generated from video freeze frames accounted for 72 percent of the counting products. The counting was performed with the assistance of

FIJI/ImageJ2 (Version 2.14), an open-source scientific image analysis software, with the process closely resembling the one used by Hodgson et al., 2018. Using the “Grid” tool under “Analyze → Tools” a grid of specified cell size was added to the image. A cell size approximately the size of one elk was utilized. The grid assisted with counting by providing columns and rows to the image that were searched by scrolling up or down columns and moving sequentially left to right. While searching, the “Multi-Point” selection tool was used to mark each animal counted. A colored dot and plus sign would appear at each click along with the tallied number (*Figure 8*). This was useful for knowing which animals had been counted and not losing track of the count, especially when pausing to review the companion video. This was increasingly useful for large herds and complex formations. The entire image was searched until all animals were counted, and the final total herd count number was tallied and recorded.

Figure 8: A subset of a grid overlaid photo with the multi-point tool used for counting.

Video

The process for counting using a single video was straightforward, although counting from video can be challenging. The process involved playing the video and mentally tallying the elk. This process resembles the ground counting process when using a spotting scope. Unlike the photos, there was no simple way to mark counted elk in the video. As a result, depending on the complexity of the video, it was necessary to perform the video count multiple times until a confident number was repeated. Specific techniques adopted from spotting scope counts were employed, such as sectioning off groups and using trees, rocks, and other features as visual markers to track counted and non-counted zones. Also, if the elk were moving, it was useful to count them as they passed by a specific feature, such as an opening in the trees. An example: On the first few plays, one would only count a group in the left portion of the frame. Once confident in that group, the number is recorded, and then, a recognizable rock could be used to section off the left group, and focus moved to the next portion of the frame and so on. When recording a small group in thick cover, typically, there was no need to pan. The key is to watch the video intently for slight movement and ear flicks.

Verification Counts

To reduce counter-bias, counts were performed by three individuals in independent settings. The author performed the initial counts using the counting products. Each exact counting product (with grids) and companion media used for each observation was supplied to Boulder County wildlife staff for verification. The initial count number was not provided. A written protocol and demonstration video were supplied to use the same software (FIJI) and general process for the independent counts. Count discrepancies were investigated and settled by reviewing the observation count product and looking for animals that were missed or double-counted by counters.

Discarded Observations

Four of 25 total observations throughout the field campaign were removed from the data analysis because the ground count/flight protocol during the observation varied from the rest of the observations enough that they could skew results. Observation 1, Oct_18_F1_1 was removed because the ground count and flight did not occur within a short enough time span. A small group of elk were seen moving through trees as we exited the vehicle and before the UAS could be launched. If the UAS was in the air at the same time as the ground count and vice versa, then it's possible the same number would have been counted. Observation 15, Feb_28_F2 was discarded because a viable ground count in the same manner as other observations was not possible, but a count from the morning was available. Elk were spotted with the drone, but it would have taken considerable time to get into position for a ground count, so in the field, it was decided to take the morning count number. After review, it was decided this did not meet the requirements for the field protocol. Similar instances occurred where elk were spotted at a considerable distance with the UAS, with no possible way to get a ground count. Indeed, these could be counted as zeros, but since no attempt was made to get into a ground count position (considerable time and effort would have been required), these also did not meet the field protocol requirements. Also, the aerial count would have been with high error because of the distance (> 2km). While not useful for statistical analysis, these observations still provide insight into the utility of the UAS for locating elk on terrain not visible from easily accessed points.

Count Difference Analysis Methods

First, a simple comparison of ground counts versus aerial counts was conducted by subtracting the ground count number from the aerial count number (count difference, CD) to see if there was a fundamental difference between the two collection methods. Next, a simple linear regression model of aerial count vs. ground count was created using the program R in R Studio (Version 2024.04.2) to further evaluate for statistical differences. A general linear model (GLM) analysis, similar to previous ungulate sightability studies, was then used to examine what factors may have affected the differences between aerial and ground counts. (McMahon, Ditmer, Isaac, et al., 2021; Terletzky & Koons, 2016).

During count collections, it was possible to see the effects of the count condition factors introduced in *Table 1*, with leading factors emerging. Based on the in-field observations, the primary factors hypothesized to cause differences in counts were ground view obscuration, the difference between the ground and UAS viewing distances, herd size, herd layout, herd status, and terrain. Ground view obscuration (GVO), viewing distance difference (VD), and herd size (HZ) were the leading suspected predictor variables and were also well-suited for statistical analysis. GVO was categorized as existing (Yes) or not (No) for an observation. VD and HZ were continuous, measured variables. Viewing distance difference (VD) was calculated by subtracting the aerial viewing distance from the ground viewing distance. Herd size (HZ) was recorded as the larger of the two counts for an observation. Utilizing herd size as a model factor also captured relative differences within the observations instead of normalizing count differences and expressing the differences as a percentage of the total herds observed. This approach sought to avoid issues with collinearity and allowed for a more robust interpretation of herd size effects. Herd layout, herd status, and terrain could not be analyzed statistically because of the ambiguity in assigning discrete categorization (i.e., the full range of each factor could be present within one observation). These factors were analyzed qualitatively using a content analysis approach.

Before the model selection process, the Shapiro-Wilk test for assessing normality for small sample size data sets was conducted in R. It showed significance for CD (p-value: 0.00012, 〈 = 0.05), indicating non-normality, ruling out a straightforward t-test analysis. GLM's were created using the glm function in R. Models comprised combinations of GVO, HZ, and VD including with or without interaction. The fit of the models was assessed using the corrected

Akaike's Information Criteria (AICc) to account for the small sample size, the residual deviance, and log likelihood. Effect plots of the best performing model was created using the PredictorEffects function in the Effects package of R.

CHAPTER III: RESULTS

Ground and Aerial Count Results

The final counting results for the *n = 21* observations analyzed are presented in *Table 2*. The mean difference between the aerial and ground counts was *28* elk with a *standard deviation of 37.4*, *a maximum of 129, and a minimum of zero*. All aerial observations except one found more elk than the ground counts. The results show a wide range of differences between the aerial and ground counting methods, with some being equal and many having significant differences. Minor differences considered six or fewer elk accounted for nine of the 21 observations (43 percent). Twelve (57 percent) of the observations found a difference of 12 or more elk.

Table 2: Number of elk counted for n = 21 observations for ground and aerial methods

Observation ID	Location	Ground Count	Aerial Count	Difference
Feb_29_F1	Red Hill, Etter	52	181	129
Nov_22_F1	E Side TBM	50	164	114
Jan_18_F1	Red Hill S	8	84	76
Jan_19_F1	Loukonen	34	89	55
Oct_18_F2	E Side TBM	17	70	53
Nov_21_F2	Imel	121	148	27
Oct_18_F3	E Side TBM	81	106	25
Feb_28_F1	Loukonen	104	127	23
Mar_1_F1	Wolf Run	150	170	20
Apr_26_F1	Red Hill	55	75	20
Mar_1_F2	W Side Haystack	59	76	17
Jan_19_F2	E Side TBM	50	62	12
Nov_22_F2_1	Red Hill	16	22	6
Apr_30_F2	Red Hill S	4	7	3
May_01_F2	W Side Haystack	33	36	3
Jan_17_F2	N 81st St	127	129	2
Nov_21_F1	W Side Haystack	10	11	1

Table 2. cont.

Observation ID	Location	Ground Count	Aerial Count	Difference
Jan_18_F2	Red Hill S	47	48	1
Oct_18_F1_2	N End Indian Mtn	6	6	0
Apr_30_F1	Rabbit Mtn Flats	7	7	0
May_01_F1	N End Indian Mtn	33	32	-1

Count Difference Analysis

Statistical Results

Linear Relationship

The results for the aerial count (AC) vs ground count (GC) linear model (*Figure 9*) indicate a consistent and statistically significant ($p < .001$) positive relationship between ground counts and aerial counts, with aerial counts exceeding ground counts by *27.6* elk on average. The R^2 value of *0.57* indicates a moderately reliable model fit.

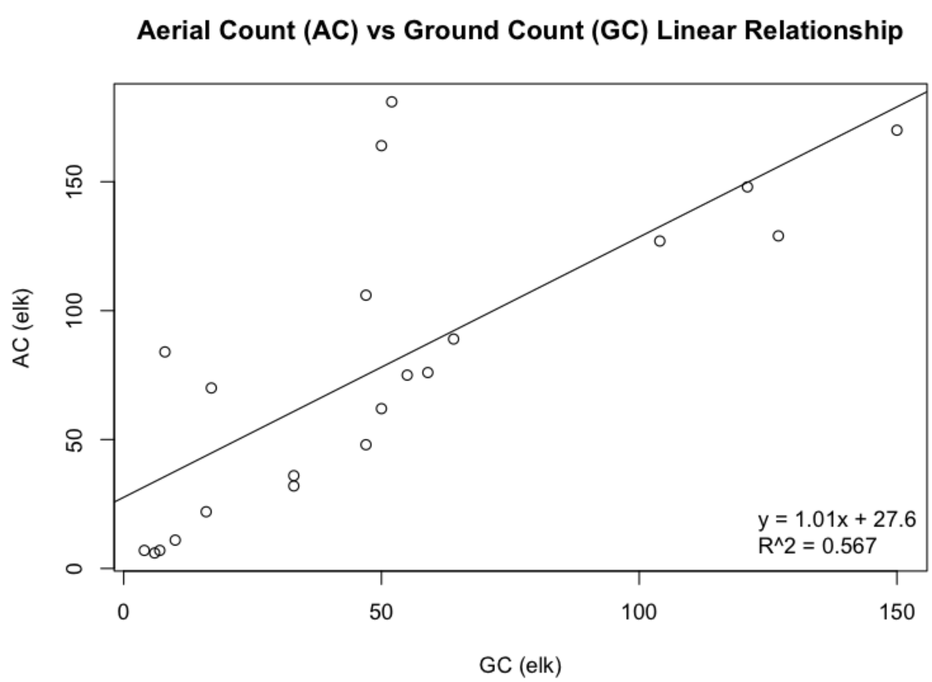

Figure 9: Plot showing the linear relationship between aerial and ground counts of elk for n = 21 observations

General Linear Model Selection Results

The best fitting factor analysis model included the main effects of GVO and HZ with the interaction between the two: GVO*HZ. This model had the lowest *AICc score*, *188.1*, which was used as the primary assessment metric. This model also accounted for a significant amount of model deviance and had a log-likelihood score on the low end compared to the other models (Field, 2018). *Table 3* shows all of the model factor combinations and respective assessment scores. The summary of the best-performing model is found in *Table 4*. The model results show that the HZ and HZ*GVO terms are significant. While the GVO-Yes category was insignificant, the interaction term, HZ*GVO, resulted in a *p-value* of *0.0004,* indicating very strong significance. This does not mean that ground view obstruction is unimportant; rather, it is highly important when considering herd size. Viewing distance difference from the elk (VD) did not appear in the top-ranked model and its effects are considered null.

Table 3: GLM factors assessed for effects on count differences, ranked by AICc scores

Model	AICc	Delta AICc	Residual Dev.*	LogLik
GVO+HZ +GVO*HZ	188.1	0.0	4891.7	-87.0
GVO+VD+HZ +GVO*HZ	191.0	2.9	4650.9	-86.5
GVO + HZ	200.5	12.4	10439.0	-95.0
GVO + VD + HZ	202.8	14.8	9891.9	-94.4
GVO+VD+HZ +VD*HZ	202.9	14.8	8191.8	-92.4
VD+HZ +GVD*HZ	204.9	16.8	10887.0	-95.4
GVO+VD+HZ +GVO*VD+HZ*VD+GVO*HZ+GVO*VD*HZ	205.8	17.7	4317.0	-85.7
HZ	206.0	17.9	15735.0	-99.3
GVO+VD+HZ +GVO*VD	206.6	18.5	9770.0	-94.3
VD + HZ	208.9	20.8	15573.0	-99.2
GVO	210.4	22.3	19379.0	-101.5
GVO + VD	212.7	24.7	18692.0	-101.1
GVO+VD+GVO*VD	212.9	24.8	15964.0	-99.5
VD	218.2	30.2	28142.0	-105.4

*null deviance for all models = 28304

Table 4: GVO+HZ +GVO*HZ statistical model summary

Variable	Estimate	Std. Error	t-value	p-value
Intercept	-0.30	7.40	-0.04	> 0.05
GVOY	-21.61	14.76	-1.46	> 0.05
HZ	0.18	0.08	2.14	< 0.05*
GVO:HZ	0.64	0.15	4.39	< 0.05***

* p < 0.05, *** p < 0.0001

The HZ effects plot (*Figure 10)* shows the effects of HZ on count difference while considering whether ground view obscuration was present. Overall, as herd size increased, discrepancies between aerial and ground counts increased as indicated by positive sloped lines in both "No"/"Yes" panels of *Figure 10*. For the "No" category of GVO, the plot shows a slight increase in CD as herd size increases. For the "Yes" category of GVO, there is a more dramatic increase in CD as herd size increases.

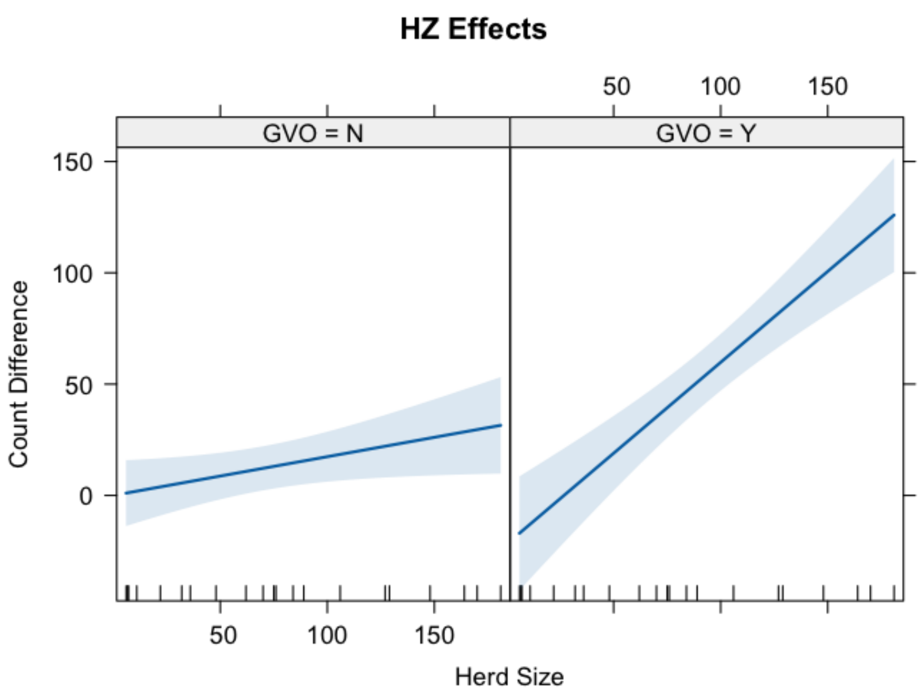

Figure 10: Effect of herd size on count difference with respect to ground view obscuration

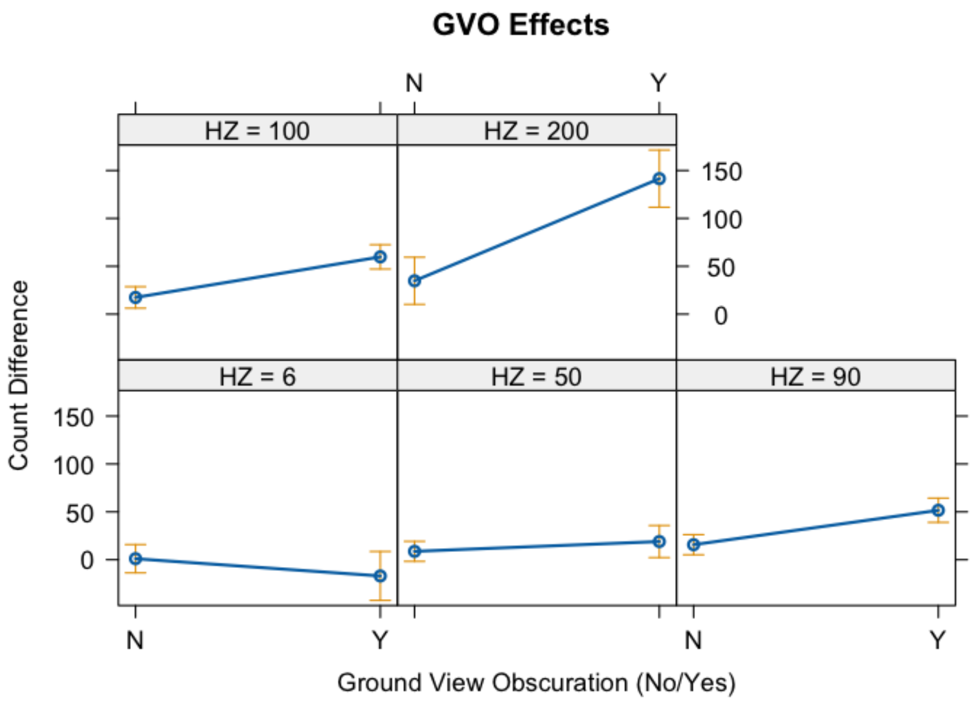

Figure 11: Effect of ground view obscuration on count difference with respect to herd size brackets

GVO was present in seven of 21 observations, with an average difference of 65 elk in the "Yes" category. The "No" category accounted for 14 of the 21 observations, with a mean difference of 9 elk. The GVO effects plot (*Figure 11*) echoes the results of HZ effects plot and shows the effect of GVO on CD with respect to herd size categories. For four of the five panels shown, the presence of GVO results in a higher count difference. The bottom left panel of *Figure 11* indicates for small herds (around 6), the presence of GVO did not increase count differences and is likely because there were no observations with GVO present in herds under seven elk. For herds of 50 and above, as herd size increased, so did the effect of GVO, as seen from the increasing count difference delta between "No" and "Yes" categories (steeper sloped line), in each herd size bucket.

Qualitative Content Analysis of Observations

The statistical analysis provided that ground view obscuration and herd size significantly contributed to the differences between aerial and ground counts. However, from field observations, it is likely that herd layout, herd status, and terrain were also contributing factors. To assess this validity, a content analysis was performed by dissecting the conditions of each observation and grouping observations with commonalities. The intent was to uncover the most impactful factors left out of the statistical analysis and validate the findings of the statistical analysis.

Observations were first grouped according to the GVO category: those with ground view blocking and those without. This was used as a starting point because GVO was a significant factor affecting CD, and it provided a mechanism to analyze the observations that had large and small differences in CD but did not have GVO. These categories are denoted as obscured large difference (OLD), non-obscured large difference (NOLD), and non-obscured small difference (NOSD). This analysis prods each suspected factor individually, but it is highly likely the effects are compounding and interrelated. The categorized observations and the associated factor data were synthesized down to Terrain Obscuration, Herd Size, Herd Formation and Status, Cover, Observation Distance Difference, and Terrain. Refer to *Table 1* for factor categorizations.

Common Factors for Observations with No Terrain Obscuration and Large Differences (NOLD): Five Observations

This category of observations found large differences between aerial and ground counts. A large difference is defined as 12 or more elk for this data set.

Herd Size: This category contained four large and one medium herd sizes. This is intuitive simply by the fact that there are more elk available to miss when the herd size is larger. The dominant large herd size category aligns with the statistical results pertaining to herd size.

Herd Formation and Status: Each observation in the NOLD category has in common that all or a portion of the herd was grouped and bunched tightly together. In addition, for four of the five under this classification, some portion of the herd was also standing and milling about, potentially blocking bedded elk.

Cover: All five observations were in very open vegetative cover indicating that other factors have more of an effect in the differences seen, since open terrain would be considered more desirable over thick vegetative cover.

Observation Distance Difference: Observation distance differences ranged from -16 m (negative indicates the ground observer was closer) to 425 m. The average difference was 186 m for the aerial observation. This indicates a potential effect for VD, but the largest difference in this category was when the viewing distance was only 16m different.

Ground to Elk Elevation Difference: For four of the five observations in the NOLD category, the elk were at the same elevation as the ground observer indicating this factor requires consideration. One observation had elk slightly above the ground observation height.

Terrain: All five observations found elk in flat or mildly sloped terrain, indicating flat terrain can lead to differences in counts.

NOLD Summary: Large grouped herds, whether bedded, standing, or both, without elevation relief for viewing, in flat terrain provide conditions for large differences to be seen.

Common Factors for Observations with No Terrain Obscuration and Small Differences: Nine Observations

This category of observations found small differences between aerial and ground counts. For this data set, a small difference is defined as six or fewer elk.

Herd Size: Slightly more than half (five of nine) of the observations in this category were of small herd sizes ranging from six to 22 animals, with three observations of medium-sized herds ranging from 32 to 48 animals. The remaining observation was of a large herd of 129 animals. This furthers the notion that lower herd sizes result in smaller ground-aerial count differences. The single large herd with a low count difference indicates that other factors have influence as well.

Herd Formation and Status: Looking at herd formation it is seen that seven of the nine observations found elk in a more spread-out arrangement, either bedded or standing/milling/feeding with herd sizes ranging from very small to large in a spread arrangement. This fits with the previous information that bunching of animals causes issues.

Cover: Cover for the NOSD category of observations included four in wide open cover, three in some level of brush, one in a semi-open burned forest, and one in a vegetated forest. The variation indicates that cover did not have a large effect on count differences, as cover potentially affected the aerial and ground observations equally. One observation occurred in thick tree cover and resulted in a count difference of 6, the highest difference of the small difference category, indicating cover could be a secondary factor when combined with other factors.

Observation Distance Difference: Observation distance differences range from zero meters to 840 m. With small count differences found and long viewing distances for ground observations, it is suggestive that VD was not a major limiting factor.

Ground to Elk Elevation Difference: Six of nine observations had elk above the ground observer, with the other three being level.

Terrain: Observations in the NOSD category were either of elk in a flat field or of elk on a hillslope facing the ground observer. Six of nine were on a hillslope, with the remaining three in a flat field. These correspond to the elevation difference factor.

NOSD Summary: The assessment for the NOSD category continues to shed light on the notion that smaller to medium herds that are not bunched tightly together result in smaller count differences. In addition, there were more observations in the NOSD category than the NOLD category that had sloped terrain with elk above the ground counter facing the elk, suggesting these could have led to smaller differences. The outlying observation in the NOSD category was observation 9, where a large herd of 129 in a flat field level with the ground observer resulted in a difference of only 2. The most notable factors here were regarding the herd formation and status: the elk were standing and spread widely throughout the field at 330m, further pointing to bunching as being a main contributing factor in differences.

Common Factors for Observations with Terrain Obscuration and Large Differences (OLD): Seven Observations

This category of observations found large differences between aerial and ground counts. A large difference is defined as 12 or more elk for this data set.

Herd Size: The OLD category contained two large and five medium herd sizes. This is intuitive simply by the fact that there are more elk available to miss when the herd size is larger, especially if terrain blocking did occur; more elk are available to be hidden.

Herd Formation and Status: Three of seven observations in the OLD category found elk bedded in bunched groups. The other four observations were of elk that were generally spread out; sometimes widely (i.e., across a span of hundreds of meters). While a spread herd could be beneficial, if terrain blocking is a factor, then the herd could be spread behind terrain and would only be beneficial for the elk that could be seen.

Cover: Six of seven observations found elk in a mixture of open cover with brush, with one in mixed habitat with open cover and some open trees. The observation that the elk were not in thick cover indicates that cover is not a significant contributor to the differences seen.

Observation Distance Difference: Observation distance differences ranged from -264 m (ground observation 264 meters closer than aerial photo) to 700 m for these seven, backing up the notion that VD was not a major factor, since observations at closer ranges for ground observations still resulted in large differences.

Ground to Elk Elevation Difference: Regarding elevation difference, observations in the OLD category found elk above, below, and level with the ground observer indicating for these six observations, blocking was likely the most contributing factor.

OLD Summary: The assessment for the OLD category reinforces the statistical finding that terrain blocking in combination with herd size were the biggest contributing factors. This is also reinforced by the number of observations that had generally favorable conditions for ground observation (medium herd, spread formations, open cover, non-level viewing angle) other than terrain blocking and still produced large differences.

UAS Elk Reaction Results

Elk reaction results are summarized in *Table 5*. Of the 23 observations where flights occurred, only one change in action and alertness status was potentially a result of the UAS. In this instance, we flew the drone directly overhead the elk group. The two other status changes (Obs. 14 and 17) were likely caused by other disturbances, such as coyotes (See *Table 5* footnotes). The other instance where we flew the drone directly overhead a group of 36 elk, did not result in any reaction (Obs. 23).

Table 5: Summary of elk action and alertness levels throughout observations

Observation	Action Prior to Flight	Alertness Prior to Flight	Action During/After Flight	Alertness During/After Flight	Drone Distance to Elk (m)
1	Transiting Slowly	Non-vigilant	No change	No change	1509
2	Transiting Slowly	Non-vigilant	No change	No change	607
3	Bedded/Grazing	Non-vigilant	No change	No change	766
4	Bedded/Grazing	Non-vigilant	No change	No change	396
5	Bedded	Non-vigilant	No change	No change	589
6*	Bedded/Grazing	Vigilant	No change	No change	482
7	Bedded	Non-vigilant	No change	No change	616
8*	Moving	Fleeing	No change	No change	219
9*	Feeding/Slowly Moving	Non-vigilant	No change	No change	216
10	Feeding/Bedded	Non-vigilant	No change	No change	322
11	Feeding/Slowly Moving	Non-vigilant	No change	No change	264
12*	Feeding/Bedded	Vigilant	Standing/Grouping	Vigilant	110++
13	Bedded	Non-vigilant	No change	No change	308
14*	Standing/Milling	Vigilant	Standing/Grouping	Vigilant	237
15	Feeding/Bedded	Non-vigilant	No change	No change	335
16	Feeding/Bedded	Non-vigilant	No change	No change	380
17*	Feeding/Slowly Moving	Non-vigilant	Moving/Grouping Up	Vigilant	658

Table 5 Cont.					
Observation	Action Prior to Flight	Alertness Prior to Flight	Action During/After Flight	Alertness During/After Flight	Drone Distance to Elk (m)
18	Bedded	Non-vigilant	No change	No change	475
19	Feeding	Non-vigilant	No change	No change	461
20	Bedded	Non-vigilant	No change	No change	806
21	Bedded	Non-vigilant	No change	No change	515
22	Bedded	Non-vigilant	No change	No change	411
23*	Bedded	Non-vigilant	No change	No change	96++

*6 Some elk stood up prior to drone launch but were looking towards opposite direction of our vehicle. No change during and after flight.

*8 Likely that we pushed the elk while we were walking through the trees; elk did not change behavior after seeing us set up or during flight.

*9 Elk were in a field close to us. They could see us while counting and launching the drone and moved toward us during the two flights and talking with residents.

*12 Some elk were vigilant on arrival counts, then all stood up later when the drone was overhead. We suspect higher initial vigilance due to a coyote nearby.

*14 Elk were vigilant during set up. Elk grouped up during flight but this was likely because of coyote seen in the aerial video.

*17 The elk were grouping up but not fleeing when we encountered them, unclear why. Drone was far away and strong wind was blowing away from them.

*23 Elk were in a good spot to try another overhead instance. Flying directly overhead, elk did not react to the drone.

++ Drone positioned directly overhead.

CHAPTER IV: DISCUSSION

Factors Affecting Count Differences

The results of the analysis primarily reflect the advantages of the aerial perspective and the agility of the UAS. The linear regression model associating ground counts and aerial counts indicated that, on average, the aerial counts found more elk and showed significance ($p < 0.01$), suggesting the results did not occur randomly and that there is an actual difference between the counts. The GLM selection process attributed the main effects to instances where terrain blocked the view for the ground observer and to observations where large herd sizes were encountered with notable interaction between the two. Observations with terrain blocking accounted for 7 of 21, with differences ranging from 12 to 129 elk. All but one of the observations that experienced terrain blocking consisted of elk located above the ground observer either in a drainage, hanging meadow, or mesa top with some elk at the edges of the top but most hidden on the elevated flat. The remaining observation had elk located at the same elevation but with a portion of the herd hidden behind a hill adjacent to the meadow (Figure *5*). In these seven observations, when flying the drone, it was quickly evident that there were elk present that could not be seen from the ground, and it was possible to easily fly the drone to an appropriate position to capture all elk seen in the video display. In all these instances, repositioning for a different ground perspective would have taken significant effort, requiring long drives or hikes and much further viewing distances. It is worth noting that even if a better ground position could be gained, typically, it would not occur because it would be unknown if additional elk were present without confirmation from the UAS.

The effect of herd size on count difference is somewhat intuitive as there is simply more mathematical room for larger differences to appear. Contextually, there are also more elk present to be missed. The interaction of herd size and terrain blocking can be interpreted as: an increase in the number of elk on the landscape increases the likelihood that some elk could be hidden behind terrain. In addition, it is possible the herd size factor captures effects from the herd formation factor that were not represented in the GLM but were assessed in the content analysis. In cases where there were large herd sizes and animals grouped tightly together, there were also large differences in counts, indicating that herd size may also account for the effects of herd formation.

Viewing distance difference was also assessed in the GLM but did not have a significant effect. Ground viewing distances ranged from 87 m to 1528 m with a mean of 710 m. For the aerial observations, the horizontal distances of the drone to elk ranged from 1500 m to directly overhead, with an average distance of 469 m. It is suspected that the longer viewing distances for the ground observer did not have a significant impact because of the high-quality optics used by the ground observer. It is plausible that the effects of herd bunching could be minimized if closer to the herd, especially for the ground method, since there was no elevated perspective to alleviate bunching issues.

The results of the qualitative content analysis complemented the statistical analysis. Where terrain blocking was not a factor, but significant differences were seen between aerial and ground counts, observations that experienced large herd sizes in tightly bunched formations and flat fields were assessed to be the root causes of the differences. The aerial perspective of the UAS was able to mitigate these effects by creating a steeper viewing angle, making it possible to see gaps between the animals, and allowing for better individual identification. Observations where animals were located on a hill facing the ground observer and/or the UAS provided a desirable viewing condition for both methods. Vegetation cover played a significant role in that the open terrain for most observations created ideal observation conditions and generally affected ground and aerial counts equally. Had many more observations been of elk in thick vegetation, the efficacy of this specific media collection tactic would have suffered but could potentially be mitigated through nadir-oriented imagery.

UAS Count Data Collection Considerations

Central to the study's success was the design and appropriate selection of the UAS. Because of the patterns of these elk herds, the open terrain, and the road access, it was possible to use the UAS primarily as a counting tool as opposed to a detection tool. There were instances where the agility of the UAS was used to find elk that were not first located on the ground, but these were left out of the comparisons because they strayed from the side-by-side count protocol. Previous studies utilizing UAS for elk population counts that followed a detection-first protocol were not successful (Cauvel, 2014; ODFW, 2017; VizionAir, 2017). Graves et al. (2021) utilized UAS for counting rather than detecting and successfully counted a large herd at the National Elk Refuge. Using a detect first, fly second approach is likely more successful when herds are congregated into larger groups and in open terrain, typically in colder months. Overall, we were more successful at finding elk during the colder months than warmer months, which echoes previous suggestions from detectability studies for elk and bison (Samuel et al., 1987; Terletzky & Koons, 2016; Unsworth et al., 1990).

UAS Media Collection

The DJI Mavic 3 Pro was selected primarily for its optical zoom capabilities and its portability. The zoom capability was a necessity as the tolerance of the elk to the drone was unknown before the field work and long viewing distances were anticipated. Having a system with zoom capability was analogous to having binoculars in the sky, thus strengthening the count method comparisons. The primary goal was to capture images at high enough resolution for individual elk discernment at distances that would not disturb the animals. Previous UAS wildlife studies noted low imagery resolution as a challenge for accurate data analysis (Elmore et al., 2023). Luckily, elk disturbance was not an issue, but in many cases, the drone was kept further away even though closer imaging distances would have been beneficial. Imaging distances ranged from 96 m (directly overhead) to 1509 m, with a mean of 469 m. The desirable drone to elk distance depends on many factors that must be assessed in situ. A primary factor of the maximum distance is the desire for either a total count or a herd composition count. Generally, determining sex and age class would require media capture distances around 200 m and using maximum optical zoom. For total counts, a distance of no more than 400 m is desirable. Other factors that affect the viewing distance are the vegetative cover, the herd formation, and sun angle. In cases where these factors are compounding, a steeper viewing angle is preferred, requiring shorter UAS to elk distances if UAS is at maximum legal height. A steeper viewing angle can reveal gaps in trees and brush cover to view animals. Images captured at a nadir viewing angle alleviated issues with bunching by visualizing gaps between animals and provided close enough imagery for potential herd composition counts (*Figure 12)*.

Figure 12: Comparison of oblique image to nadir image of elk herd. Above, elk were imaged from 595 m line of sight at max optical zoom (7x). The elk bedded furthest away appear bunched because of the angle and are more difficult to count.Below, the same herd imaged from 110m directly above (no zoom) reveals gaps between animals, making it easier to count individual elk once zoomed in on a computer screen.

While maximum resolution and nadir imagery were preferred, this had to be weighed against collecting imagery that provided the cleanest scene possible so that the downstream digital counting process was not overly cumbersome or inaccurate. Field conditions force a balancing act between maximum resolution, viewing angle, and maximum field of view, which is affected by viewing distance and herd formation complexity. For example, a simple scenario of a group of 10 animals bedded closely would allow for maximum zoom level and only a few photos or videos to be captured, only requiring a single high-resolution image for review. In contrast, a larger group with some animals bedded and some milling about and moving, or all moving, would require either less zoom (lower resolution) and fewer photos or higher zoom and multiple overlapping photos or long videos to ensure that the whole herd is covered. The most challenging scenes involved large herds in less than open vegetative cover, spread across a hillslope, that were standing, moving, and in places bedded tightly together with some in shadows, with the camera facing into the sun. Each of these conditions requires a separate acquisition adjustment while considering the others. With this in mind, and because of initial disturbance limitations, it was impossible to gather high enough resolution imagery in many scenes to properly classify each elk by age and sex. This was also a challenge for ground counts, especially in bunched areas at equal elevation, and as a result, herd composition comparisons were not possible or focused on.

The quality of the aerial media collected directly affected the counting precision. For most aerial observations, there was little difficulty in individual elk discernment. Results of the verification counts showed six of 21 observations having no differences between counters, ten of 21 with two of three counters arriving at the same number, and five of 21 observations having all three counters arrive at more than one animal difference minimum and a maximum of difference of 12. The observations with the highest discrepancies within the aerial imagery were of elk in similar and complex settings: medium to large herd sizes with some portions of the herds being bunched tightly together. Other notable conditions that increased digital counting difficulty were animals hidden in shadowed areas and when the sun was low on the horizon facing the camera orientation at capture (late afternoons).

The methods developed for capture and review included published recommendations for reducing availability and perception errors within UAS media. They were valuable suggestions, as indicated by the low number of discrepancies. Mitigation methods for this include surveying when animals are in open areas, using a secondary counting or validation method, and by performing multiple manual reviews of aerial imagery, all of which were adopted here and should continue to be used for future studies if possible (Brack et al., 2018). Availability errors occur when animals that are present are not detected, usually due to thick vegetation or movement outside of the study area. Perception errors can occur during the imagery review process, where animals cannot be identified in the imagery, which would be due to human error in this review process.

Disturbance Discussion

Maintaining a satisfactory separation distance was key to avoiding negative elk response, thus requiring a UAS with zoom capability. During the beginning of the campaign, we maintained overly cautious distances (600 m or more) and increased distances slowly over the campaign. With no literature on elk response to UAS, the team's experience was utilized to gauge aircraft noise and elk behavior. When no negative responses were seen, the team decided it was desirable to move closer to the groups with the UAS to gather higher quality imagery and only when the elk were in a location that, if fleeing occurred, would not cause harm (i.e. not close to busy roads or fences).

On two occasions, the drone was flown directly overhead the elk, near the maximum allowable altitude, allowing for nadir shots of the elk and to assess behavior this close to the elk. On the first occasion, during observation 12, the group was partially bedded and standing, with about ten animals on the mesa top's edge, indicating vigilance before a flight. We are confident the pre-flight vigilance was due to a coyote and our presence. We saw a coyote in the valley below the elk, and the vigilant elk were looking towards the coyote's direction. We were also set up in the open 600 m across the valley from the group and could be seen. We slowly approached with the UAS, and a few started to stand. Then, after no fleeing reaction was seen, we proceeded to fly and hover above the partially bedded herd. After a few minutes of overhead hovering at 110 m, all the elk stood. At one point, some elk started to move quickly but stopped, and no other actions were seen. The elk remained standing and in place until we vacated the area approximately 20 minutes later. The second occasion, when the drone was flown directly over the elk (observation 23), did not result in any noticeable reaction, which was confirmed through the video recording directly overhead.

The overall lack of reactions to the UAS is not surprising given the distances of observation and because of the exposure to constant human stimulus present in their environment, including low-flying aircraft and noisy vehicles (Schroeder et al., 2020). Future studies using UAS for elk research in more remote areas may not experience the same result and should practice caution with initial flights, including following suggestions by Hodgson and Koh (2016) for minimizing disturbance to wildlife.

In addition to elk, disturbance to raptors was also accounted for. On many occasions, raptors were in the vicinity of flights although flights were never conducted near known raptor nesting sites. No evidence of disturbance to raptors was found. No aggressive or decisive change in behavior was witnessed during the campaign, suggesting the raptors were not threatened by or interested in the drone.

Conclusions

Previous wildlife studies have also found UAS-derived count data to be more accurate compared to ground counts while also providing operational advantages and a positive argument for the use of UAS in further elk and wildlife studies (Graves et al., 2021; Hodgson et al., 2018; McCarthy et al., 2022; Preston et al., 2021). The ability to navigate terrain and vegetation to provide an optimal viewing angle for detected elk or to discover elk not detected at all previously is the primary advantage of the UAS. Launching a drone can replace the need to relocate by driving or hiking across rugged terrain, providing higher efficiency and safety to counting operations. Capturing digitally recorded imagery of herds for review in an office setting offers the advantage of computer-assisted counting that can be repeated without the hindrance of field conditions (Terletzky & Koons, 2016). Digital records of the herds also provide the ability to monitor herd behavior and precise positioning of herds through geo-tagged photos. UAS also offer the advantage of causing less disturbance than capturing and GPS-collaring animals and hiking close for a ground count. In addition, for future studies, UAS could alleviate disturbance caused by helicopter-based surveys seeking to count large groups of animals from the air (Van Hoose, 2024).

Programmatic burdens and operational limitations exist for UAS that must be considered. Modern UAS with complex sensors are becoming easier to operate but require hands-on and regulatory training. For this targeted media acquisition protocol, it is advised to become intimately familiar with the aircraft operation, especially the camera gimbal and zoom operation prior to counting deployment. This was essential for capturing high-quality imagery. In addition, an FAA-issued Part 107 Remote Pilot Certificate must be held by the pilot-in-command of the operation, as well as liability insurance, all of which require time and financial investments. Permits were required for flying on Boulder County property and were coordinated in advance of each mission week. Many local agencies require such permits in addition to FAA regulations. Crash risks such as damage to private property and fires from lithium batteries exist but can be minimized with proper training, experience, and conservative flying. Adhering to manufacturer limitations of the UAS for wind and temperature is also critical for operation in harsh environments. We were constantly concerned with wind due to the field location in the foothills and frequently utilized an anemometer. Flying in the winter was challenging, especially for the operator's hands, due to low temperatures but also due to drone battery temperature thresholds.

FAA regulations for UAS can create challenges for elk surveying in large territories due to the 400 ft above terrain limitation and rules for maintaining visual line of sight. UAS worked very well on the Front Range of Colorado because of the generally open and rolling terrain, where line of sight could easily be maintained and extreme variations in altitude were not required. Pre-planned takeoff and landing points were not usually possible due to the unknown locations of elk before missions. At times, a short hike was necessary to find a suitable launch location to ensure adherence to regulations. A portable drone and launch pad was essential in accessing locations that met the minimum requirements. All these considerations will be exacerbated in vast areas with thick timber and were challenges noted by previous ungulate UAS studies (Cauvel, 2014; Elmore et al., 2023; McMahon, Ditmer, Isaac, et al., 2021; ODFW, 2017; VizionAir, 2017). An additional burden of UAS-collected data compared to ground count data is the need for an organized digital file storage and backup system. Modern UAS cameras create large files that can quickly become cumbersome if not prepared and stored properly.

Future investigations on this topic should explore the feasibility of performing mapping-style missions for orthomosaic data acquisition of herds. This study did not perform these types of missions for a number of reasons. First, this study needed to be cautious with animal disturbance in the beginning stages of the project, and thus, direct overflight of the animals was avoided on most occasions. Next, many times, the launch to elk distance was great enough that if flown directly overhead, there was a risk of losing sight of the drone, which would legally violate FAA regulations. Lastly, building an automated photogrammetric flight plan in-situ would present a challenge because elk locations varied from day to day. Elk typically are not stationary in one location, and determining the exact location and extent of the flight plan would lead to lengthy pre-flight setup times that, in some cases, could simply not be accommodated due to moving animals or weather conditions. For this study, disturbance to the animals would be less of a concern but could still present a challenge.

The use of computer-assisted image analysis and, specifically, the development of convolutional neural network (CNN) algorithms for feature extraction within imagery of large mammals is currently being conducted (Lenzi et al., 2023). CNNS were not explored for this study because source data varied between video and photos, and herds were generally small enough that the manual review of digital imagery was manageable. It would, however, be interesting to see how well CNNs would perform on this dataset given the range of zoom levels and camera angles collected. Thermal imaging is also a popular area of investigation for UAS ungulate studies and may work well for mapping style data capture as opposed to targeted and oblique image capture because of the lower resolution available in thermal cameras compared to RGB cameras (Blum et al., 2024; Larsen et al., 2023; McMahon, Ditmer, & Forester, 2021; McMahon, Ditmer, Isaac, et al., 2021).

This is the first study of multiple and recurring side-by-side comparisons of ground counts to UAS counts of North American elk. This study was designed to utilize the UAS primarily as a counting tool as opposed to a detection tool. It included the development of field media collection, processing, and review protocols. The aerial imagery results offered a significant improvement over currently used ground methods due to the aerial perspective and agility of the UAS system. The aerial imagery consistently found more elk than the ground observations, sometimes drastically more. With raw count data providing a basis for elk population modeling that influences management decisions, the implications of the differences between the aerial and ground counts are considerable. This study has shown explicitly that UAS can be successfully implemented as a tool for population counts where large herds of animals congregate, and suggests that improvement in population modeling through a reduction in visibility bias is possible by implementing UAS (Schoenecker & Lubow, 2016). In addition, for elk living in areas near human activity, a small quadcopter did not disturb the elk when cautious flying was practiced. These protocols, in concert with the explored limitations, could be implemented within Boulder County's elk management program and modified for other management programs.

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