Inter-Research Science Publisher

Endangered Species Research
Volume 56:135–144

Published March 6, 2025
https://doi.org/10.3354/esr01387

OPEN ACCESS

Detection of the Endangered black-footed ferret *Mustela nigripes* using thermal-infrared cameras

Jesse Boulerice[1,*], Kristy Bly[2], Shawn Jepson[3], Peter Mahoney[4], Jessica Alexander[1], Tevin Messerly[5], Hila Shamon[1]

[1]Smithsonian's National Zoo and Conservation Biology Institute, Front Royal, Virgina 22630, USA
[2]World Wildlife Fund, Bozeman, Montana 59715, USA
[3]Teledyne FLIR, Goleta, California 93117, USA
[4]NOAA NMFS Alaska Fisheries Science Center, Seattle, Washington 98115, USA
[5]Fort Belknap Fish and Wildlife Department, Harlem, Montana 59526, USA

ABSTRACT: Evaluating how emergent technologies can complement traditional methods for detecting wildlife is particularly valuable when population management is based on detection-based metrics for rare or cryptic species of conservation need. The black-footed ferret (ferret; *Mustela nigripes*) is an Endangered species whose rarity and behavior (e.g. semi-fossorial and nocturnal) challenge our ability to monitor individuals and assess the status of populations. Here, we evaluated how applying the emergent technologies associated with thermal-infrared cameras can be used to detect ferrets in a reintroduced population on the Fort Belknap Indian Reservation, Blaine County, Montana, USA. We conducted nighttime surveys for ferrets using thermal-infrared cameras mounted to a tower and unmanned aerial vehicles (UAVs). We recorded 7 ferret observations using a stationary tower at a rate of 0.43 observations per survey hour. At least 5 individual ferrets were observed using this method for a rate of 0.31 individuals observed per survey hour. Similarly, we recorded 8 ferret observations using UAVs for an observation rate of 0.41 observations per survey hour. At least 6 individual ferrets were observed using this method for a rate of 0.31 individuals observed per survey hour. Our findings suggest that the use of thermal-infrared cameras could benefit conservation and management efforts for the ferret or other similar species, providing a tool for detecting these elusive species that creates less disturbance to the landscape and alleviates potential navigation challenges associated with ground-based survey methods. The use of thermal-infrared cameras deployed as described here could therefore serve to complement traditional survey techniques for this Endangered species.

KEY WORDS: Black-footed ferret · Thermal-infrared cameras · UAVs · Endangered species · Conservation

1. INTRODUCTION

Effectively detecting wildlife to monitor population trends is often paramount to conservation and recovery efforts (Pollock et al. 2002, Buckland et al. 2005). Reliable methods to quantify population attributes such as local abundance, reproductive success, survival, or other detection-based metrics are especially important to rare species that are reintroduced, translocated, threatened, or endangered, where these population state variables are frequently used to gauge the progress of conservation, assign timely management efforts, or consider alternative management actions (Schwartz 2008, Thompson 2013, Berger-Tal et al. 2020). In cases where these rare species exhibit cryptic morphologies or elusive behaviors, traditional survey methods can be hampered by inefficient or laborious detection methods, high rates of false absences, or limitations to sampling efforts imposed by lack of time, resources, or personnel (Gu & Swihart

*Corresponding author: boulericejt@si.edu

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2004, Mackenzie 2005, Mackenzie et al. 2005, Schaub et al. 2007, Vine et al. 2009, Karp 2020). Wildlife conservationists should routinely consider how emergent technologies and contemporary survey techniques might improve efforts to quantify and evaluate the status of populations, especially for rare species (Pimm et al. 2015, Lahoz-Monfort et al. 2019).

The black-footed ferret *Mustela nigripes* (hereafter ferret) remains one of the most threatened mammals in North America. Classified as Endangered by the IUCN (Belant et al. 2015), current estimates suggest that less than 400 individuals occur in the wild, distributed throughout several reintroduced populations (US Fish and Wildlife Service 2019). The ferret and its primary prey, the prairie dog *Cynomys* spp., are highly vulnerable to the impact of sylvatic plague *Yersina pestis*, an exotic disease that devastates populations throughout the grassland ecosystems where they occur (Antolin et al. 2002, Jachowski & Lockhart 2009, Eads & Biggins 2015). Conservation and management of ferrets requires routine survey efforts designed to detect ferrets, where detections are used to estimate abundance, assess the viability of reintroduced populations, conduct important vaccination efforts, and assign critical management actions including disease mitigation, population supplementation, or translocation (Black-Footed Ferret Recovery Implementation Team 2016). The recovery of this species is based on the ability to detect and count the number of breeding adults currently alive in the wild (US Fish and Wildlife Service 2013).

Due to the elusive behavior of this rare, nocturnal, semi-fossorial, and small-sized mustelid, few survey techniques are available that provide reliable detection of ferrets. The primary survey method for this species consists of nighttime spotlight surveys using hand-held or truck-mounted spotlights to detect individuals during infrequent aboveground bouts (Grenier et al. 2009, Jachowski et al. 2010, Black-Footed Ferret Recovery Implementation Team 2016). Other methods such as the use of scent-detection dogs (Reindl-Thompson et al. 2006), snow tracking (Clark et al. 1984, Richardson et al. 1987), trail camera stations, and environmental DNA sampling, have been evaluated for this species, but each has been found to have limited value for enhancing detections of ferrets (Black-Footed Ferret Recovery Implementation Team 2016). As a result, spotlight-based searches are currently considered the most effective method for detecting and monitoring populations of ferrets (Black-Footed Ferret Recovery Implementation Team 2016). This survey method frequently requires repeatedly traversing off-road, often by vehicle. This extensive off-road vehicular traffic has potential negative implications associated with the spread of diseases or invasive plants, soil compaction, damage to ground-nesting birds, and general disruption to grassland ecosystems (Mack 2011, Scholten et al. 2019, Scholtz & Twidwell 2022). More generally, nighttime spotlight surveys can be physically challenging to conduct, require extensive personnel to complete effectively, and can be hampered by low detection rates. Therefore, efforts to identify survey techniques that may complement spotlight surveys are warranted and important to recovery efforts for this Endangered species.

Rapidly advancing technologies associated with thermal-infrared imagery, coupled with the reduction in size and cost of thermal-infrared camera systems, is quickly revolutionizing our ability to locate and count wildlife species (Anderson & Gaston 2013, McCafferty 2013, Christiansen et al. 2014, Christie et al. 2016, Seymour et al. 2017, Hodgson et al. 2018). By detecting infrared light emitting from warmer objects (i.e. endothermic animals) against cooler backgrounds, thermal-infrared imagery may provide advantages to detecting nocturnal wildlife when the environmental temperature is reduced at night (Stark et al. 2014, Burke et al. 2019). Thermal-infrared cameras used in hand or attached to vehicles, towers, or unmanned aerial vehicles (UAVs) have been shown to improve detection rates or provide other methodological benefits for a collection of large to medium-sized mammals such as marsupials (Corcoran et al. 2019, Brunton et al. 2020), ungulates (Focardi et al. 1973, Lhoest et al. 2015, Chrétien et al. 2016, Beaver et al. 2020, Obermoller et al. 2021), primates (Spaan et al. 2019, Semel et al. 2020, Jumail et al. 2021), mesocarnivores (Bushaw et al. 2019), and pinnipeds (Seymour et al. 2017, Edwards et al. 2021), among others. Studies examining the propensity of thermal imagery to benefit survey efforts for small (i.e. <2 kg), cryptic, and nocturnal wildlife species are less common, but include birds (Lee et al. 2019, Scholten et al. 2019, McKellar et al. 2021), lagomorphs (Karp 2020, McGregor et al. 2021), bats (Huzzen et al. 2020), and gliders (Vinson et al. 2020). To date, the use of thermal-infrared cameras has never been comprehensively evaluated for detecting ferrets.

In this study, we examined the effectiveness of 2 different implementations of thermal-infrared cameras as a tool for detecting and monitoring ferrets. First, we surveyed ferrets using a thermal-infrared camera attached to an elevated, stationary, tower. Second, we used thermal-infrared cameras mounted to UAVs to produce an elevated and mobile vantage point during searches. In both implementations, we predicted that thermal-infrared imagery would be able to detect ferrets and would provide survey attributes that could complement existing traditional methods by lessening the disturbance on grassland landscapes during survey sessions, providing an elevated vantage point that utilizes heat signatures for detections, and offering a solution to navigating difficult terrain during routine spotlight-based surveys.

2. MATERIALS AND METHODS

2.1. Study site

Our research was conducted on the Fort Belknap Indian Reservation, Blaine County, Montana, USA, during October 2022 and 2023. Fort Belknap is the homeland of the Nakoda and Aaniiih people. As part of the North American Great Plains region, this semi-arid area was characterized by flat to undulating grassland underlain by glacial till and alluvial bottomlands. The vegetative community consisted of mixed-grass grassland comprised of western wheatgrass *Pascopyrum smithii*, blue grama *Bouteloua gracilis*, and needle and thread *Hesperostipa comata* grasses interspersed with silver sagebrush *Artemisia cana* and scarlet globemallow *Sphaeralcea coccinea*, wooly plantain *Plantago patagonica*, and American vetch *Vicia americana* (Olimb et al. 2022). Our study site consisted of a 4 km^2 portion of a 7.6 km^2 colony of black-tailed prairie dogs *Cynomys ludovicanus* (48.365928° N, −108.838082° W; Fig. 1). This study site contained 15 of 22 individual ferrets observed within the colony in 2021 (T. Messerly unpubl. data).

2.2. Study design

In order to estimate the number of ferrets available to detection during surveys using thermal-infrared cameras, we conducted traditional spotlight surveys for following standard practices to estimate population size within our study site (Black-Footed Ferret Recovery Implementation Team 2016). We conducted these spotlight surveys during 2–9 October 2022 and 5 October 2023 to coincide with our thermal-infrared camera surveys describe below. We drove vehicles equipped with roof-mounted spotlights (Model RM 240 Blitz, Lightforce Professional Lighting Systems) along existing dirt roads and offroad using circular or transecting patterns to systematically survey the entire colony, including our study site, repeatedly throughout a series of consecutive survey nights. Each vehicle contained either 1 person who served as both driver and spotlight oper-

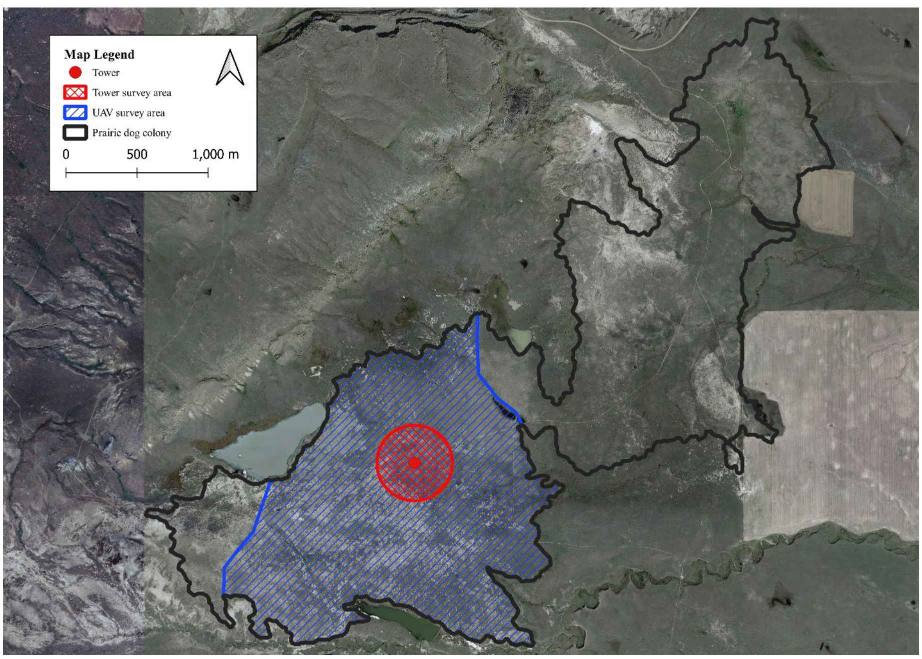

Fig. 1. Study site and survey area used to evaluate thermal-infrared camera mounted to a tower and thermal-infrared cameras mounted to unmanned aerial vehicles (UAVs) during surveys conducted for black-footed ferrets *Mustela nigripes* on the Fort Belknap Indian Reservation, Blaine County, Montana, USA, during October 2022 and 2023

ator or 2–4 people with 1 driver and multiple spotlight operators. We operated vehicles at speeds <10 mph (<16 km h^{-1}) and used a sweeping pattern with the spotlight to scan back and forth at approximately 180 degrees in front of the vehicle. We detected and distinguished ferrets from other wildlife by their characteristic emerald-green colored eyeshine. Once this eyeshine was detected, we carefully approached the animal to confirm the species identification and location. Where ferrets were detected, we placed either a live-trap or pass-through reader for passive integrated transponders (i.e. PIT tags; Industrial Reader) to identify individual ferrets. We reported survey effort for these spotlight surveys as the total number of hours spent surveying per vehicle for the entire colony. Due to the manner by which time spent surveying was recorded, we were unable to assess survey effort for spotlighting surveys specifically within our study site. All live trapping was conducted under US Fish and Wildlife Service Endangered Species Permit TE26376D-0 and Smithsonian's National Zoological Park Animal Care and Use Committee protocol SI-23045.

We evaluated 2 methods for deploying thermal-infrared cameras — mounted to a stationary tower or UAVs — to detect ferrets. We conducted surveys using this equipment within the hours of approximately 00:00–05:00 during 5–8 October 2022 and 6–9 October 2023.

Our setup for mounting a thermal-infrared camera to a stationary tower consisted of a single tower created by installing a metal tripod stand (The Defender Tripod Stand, Big Game Treestands) positioned near the center of the study site (Fig. 1). We affixed a Tau 2 (640 × 512, 30 Hz; Teledyne FLIR) thermal-infrared camera with a 100 mm lens to a PTU-5 pan tilt unit (Teledyne FLIR) using a custom-built housing to mount the pan tilt unit to the tower at a height of 3.8 m. The pan tilt unit allowed for 360° horizontal rotation and +/−90° vertical rotation of the camera. We controlled the Tau2 and pan tilt unit using a TRK-101P controller (Teledyne FLIR) and powered both using a Jackery Explorer 2000 Pro solar generator (Jackery).

During survey sessions, we searched for ferrets using this system by slowly rotating the camera 360° horizontally and between 30° and 50° vertically from the ground to systematically scan the portion of the study site around the tower. The field of view of the camera allowed us to view a maximum distance of approximately 400 m in all directions. The camera operator was positioned inside a vehicle parked at the base of the tower. We continuously monitored the live feed of the Tau 2 on a laptop (Lenovo ThinkPad; Lenovo) using the RTSP video stream from the TRK-101P to detect heat signatures of any wildlife captured in the field of view. We used a grayscale color pallet when monitoring the live feed where heat signatures appeared as clusters of white pixels against a dark background or black against a lighter background.

Our setup for UAV-based surveys consisted of 2 distinct UAVs and thermal-infrared camera payloads. For our first setup, we deployed a Matrice 300 RTK (DJI) equipped with a H20T thermal camera (640 × 512, 30 Hz, 13.5 mm; DJI). Our second setup consisted of a Switchblade-Elite Tricopter (Vision Aerial) equipped with a WIRIS Pro thermal camera (640 × 512, 30 Hz, 13 mm; Workswell). In 2022, only the Matrice 300 RTK with the H20T thermal-infrared camera payload setup was used during surveys. In 2023, both UAVs and cameras were used simultaneously, each operated by a separate pilot. The Matrice 300 RTK was powered by 2 interchangeable batteries while the Switchblade-Elite Tricopter was powered by a single battery allowing roughly 30 and 25 min of flight time, respectively. We recharged backup batteries in real-time to minimize the downtime between flights. Both UAVs were equipped with external LED lights which allowed for unaided visual line-of-sight to be maintained for both UAVs during flights at a maximum distance of approximately 1.5 km from our ground control station.

During survey sessions, we manually navigated each UAV along transects or in a circular route to systematically survey our study site (Fig. 1). When multiple UAVs were in operation simultaneously, we assigned distinct survey areas within the study site to each pilot to avoid collision and ensure that observations were not duplicative. We maintained a flight altitude of approximately 20 m above ground level and a flight speed of 10–15 km h^{-1}. We periodically rotated the angle of the camera with respect to the ground from 0° directly downward to approximately 50° forward during flight. We elected to manually fly routes as opposed to automated flight missions (i.e. pre-programmed flight paths) so that pilots could be more responsive to heat signatures of interest when first observed. We monitored real-time UAV video feeds for wildlife heat signatures, transmitted from camera payloads to ground control stations with integrated monitors through a 2.4 GHz radio link. We utilized 2 color palettes to aid the detection of wildlife, either a purple–orange palette with orange representing hot, or a grayscale color for cooler temperatures and a red color for high temperatures.

We established a real-time on-the-ground verification process designed to confirm species identification and identify the number of individual ferrets detected based on observations made during thermal-infrared camera surveys for both the tower and UAV-based platforms. Specifically, any time a heat signature thought to be a ferret was observed by the tower operator or drone pilot, we immediately relayed the coordinates of the observation to nearby personnel. This team navigated to the relayed location to obtain a visual observation and confirm species identification. We used this verification process to ensure that other species with morphological similarities to ferrets also present at our study site (i.e. long-tailed weasel *M. frenata*, swift fox *Vulpes velox*, American badger *Taxidea taxus*, mountain cottontail *Sylvilagus nuttallii*) were not misidentified from the video feeds of the thermal-infrared camera. Where ferrets were detected, we placed either a live-trap or pass-through reader for PIT tags to identify individual ferrets observed via thermal-infrared camera.

2.3. Detection metrics

We calculated the total number of observations of ferrets, regardless of uniqueness of individual, and the total number of individual ferrets observed using thermal-infrared cameras mounted to a tower and UAVs. We considered an observed ferret to be a unique individual when either multiple ferrets were observed at the same time (therefore all animals are unique) or where an observation was confirmed to a unique individual as identified by subsequent live-trapping or detection of a unique PIT tag. We standardized these values by survey effort by dividing the number of observations and number of individual ferrets observed by number of survey hours spent operating the thermal-infrared cameras over all surveys. When calculating survey hours, we only included time spent actively operating the thermal-infrared cameras and excluded time spent changing batteries, troubleshooting equipment, or other downtime in this calculation. Because we obtained a relatively small number of observations using each UAV platform independently, we pooled data from our 2 UAV platforms into a single metric.

3. RESULTS

The results of our spotlight survey efforts indicated that at least 21 and 23 individual ferrets were present within our study site during the time of survey in 2022 and 2023, respectively. We obtained these data following 9 nights and approximately 247 h of surveys in 2022 and 6 nights and approximately 127 h of surveys in 2023 distributed through the entire colony.

In a total of 16.0 survey hours, we recorded 7 observations of ferrets at a rate of 0.43 observation per survey hour and observed at least 5 individual ferrets at a rate of 0.31 individuals observed per survey hour using a thermal-infrared camera mounted to a stationary tower (Table 1). We identified ferrets by their long, slender body shape and undulating movements as viewed in the heat signatures at distances ranging from approximately 150–400 m from the tower (Fig. 2). We found that determining the specific location of the animal was challenging since the camera was stationary and did not allow for real-time distance calculations between the tower and animal. We also found that wind speeds of greater than 32 km h^{-1} challenged our ability to get clear visuals of ferrets observed beyond 250 m due to wind-induced movement of tower and camera.

In a total of 19.3 survey hours, we recorded 8 observations of ferrets at a rate of 0.41 observation per survey hour and observed at least 6 individual ferrets at a rate of 0.31 individuals observed per survey hour when using a thermal-infrared camera mounted to a UAV (Table 1). Of these observations, we recorded 5 using the Matrice 300 RTK and 3 using the Switchblade-Elite Tricopter. We found ferrets were easily identified in the live video feed of the ground control

Table 1. Summary of metrics used to assess the effectiveness of thermal-infrared cameras mounted to a stationary tower and mobile unmanned aerial vehicles (UAVs) during nighttime surveys for the Endangered black-footed ferret *Mustela nigripes* at the Fort Belknap Indian Reservation, Blaine County, Montana, during October 2022 and 2023. The number of unique individuals detected by either stationary towers or unmanned aerial vehicle is not cummulative as some individuals may have been detected by both methods independently. Obs.: observations

Method	Year	Survey effort (h)	Obs.	Ind.	Obs. h^{-1}	Ind. h^{-1}
Tower	2022	8.0	4	3	0.5	0.38
	2023	8.0	3	2	0.38	0.25
	Total	16.0	7	5	0.43	0.31
UAV	2022	7.0	5	4	0.71	0.57
	2023	12.3	3	3	0.24	0.24
	Total	19.3	8	6	0.41	0.31

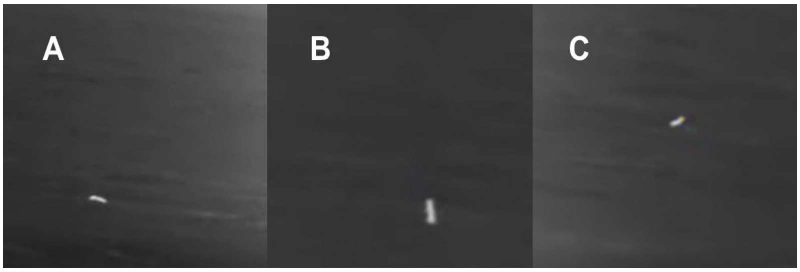

Fig. 2. Screenshots of 3 black-footed ferrets *Mustela nigripes* detected using a Tau 2 thermal-infrared camera (Teledyne FLIR) mounted to a stationary tower during surveys conducted on the Fort Belknap Indian Reservation, Blaine County, Montana, USA, during October 2022 and 2023. We detected black-footed ferrets at distances of approximately 150–400 m, including distances of (A) 150 m, (B) 180 m, and (C) 220 m from the stationary tower

station using either UAV setup we evaluated. The body shape, size, and characteristic movement patterns (i.e. darting, undulating) were clearly visible in the heat signatures produced by ferrets especially relative to the cooler background landscape present during our nighttime survey sessions (Fig. 3). We utilized the 4× and 8× zoom on either camera system to visualize detailed features of the ferret, including legs and tail. The mobility of the UAV also allowed us to navigate closer when necessary to improve visualization of the animal and collect precise GPS coordinates of the location of the animal that could be shared with the on-the-ground team.

We verified species identification using on-the-ground visual observations, live-trapping, or PIT tag reading for 5 of the 7 observations made using thermal-cameras mounted to a tower and 6 of the 8 observations made using thermal-infrared cameras mounted to UAVs. We recorded no instances where an observation made by thermal-infrared camera thought to be a ferret was misidentified as another species. Unverified observations occurred when the animal detected by thermal-infrared camera retreated into a burrow before species identification could be verified. Because of the similarities in appearance, movement patterns, and behaviors, we were confident that those unverified observations were also ferrets. In 4 cases, we reported observations of ferrets located within 50 m in space and 15 min in time by both tower and UAV-mounted infrared cameras. These observations represented 4 unique individuals independently detected by both techniques nearly simultaneously.

4. DISCUSSION

This study represents the first demonstration of thermal-infrared cameras mounted to towers or UAVs being used to detect ferrets, a small-bodied, and elusive mammal whose management requires frequent information based on detection of this Endangered species. We found that thermal-infrared cameras mounted to either an elevated and stationary tower

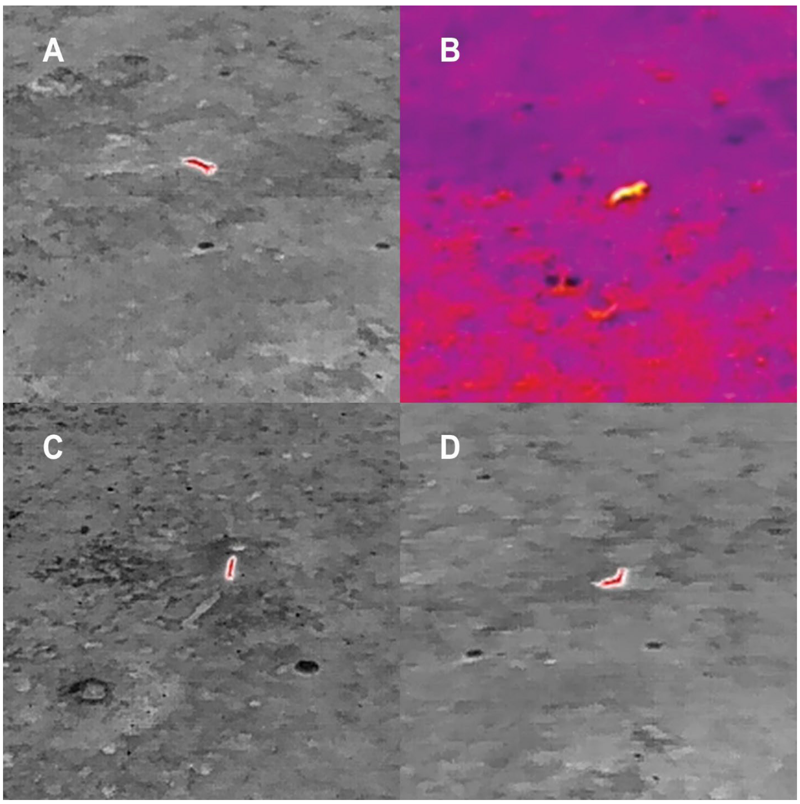

Fig. 3. Screenshots of 4 black-footed ferrets *Mustela nigripes* detected from the live-video feed of ground control stations of thermal-infrared cameras mounted to unmanned aerial vehicles during surveys conducted at the Fort Belknap Indian Reservation, Blaine County, Montana, USA, during October 2022 and 2023. Screenshots (A) and (B) display images captured using a Matrice 300 RTK (DJI) equipped with a H20T thermal camera (DJI). Screenshots (C) and (D) display images captured using a Switchblade-Elite Tricopter (Vision Aerial) equipped with a WIRIS Pro thermal camera (Workswell)

or an elevated and mobile UAV could be effectively used to detect ferrets during infrequent aboveground bouts. While traditional methods such as spotlight-based surveys will continue to be a practical technique for routine monitoring and management of this species, these findings suggest that the incorporation of emergent technologies such as thermal-infrared cameras can serve to aid survey efforts for ferrets or similar species.

The utility in mounting thermal-infrared cameras to either a tower or UAV for detecting ferrets varies by virtue of the mobility of either technique. For instance, the stationary nature of a thermal-infrared camera mounted to a tower as used here limits the spatial scale of detections to a defined radius of approximately 400 m. Therefore, towers may best complement traditional survey methods if installed where applications are similarly limited in spatial scale, such as in areas where litters are expected to occur and estimates of kit production is the primary objective. Alternatively, a network of multiple towers could be deployed to cover larger spatial scales but would require significantly more resources to utilize effectively (i.e. additional equipment and personnel to operate). Conversely, the mobility of thermal-infrared cameras mounted to a UAV provides a tool capable of detecting ferrets over larger spatial scales and provides some navigational benefits compared to traditional survey methods. When using UAVs, obstructions such as hills, ravines, vegetation, rough-terrain, or fence lines that would otherwise present logistical challenges to navigation during ground-based surveys are easily overcome using this mobile, flight-based method. This benefit may be especially valuable where populations of ferrets occur in small and fragmented habitat (i.e. prairie dog colonies) separated by sagebrush, grassland grasses, difficult terrain, or areas where vehicular use is restricted. However, in cases where spotlight-based surveys are unimpeded by logistical challenges, the use of UAVs may be redundant.

Importantly, we note that although we found thermal-infrared cameras could be used to detect ferrets on the landscape, additional steps would be required to use these tools to perform the routine population surveys and vaccination efforts typical of ferret reintroduction efforts. The traditional method used to monitor ferret populations relies on first detecting animals using spotlight surveys, followed by targeted live-trapping or installation of pass-through readers for PIT tags to capture or identify individuals when estimating population abundances and administering vaccinations (Black-Footed Ferret Recovery Implementation Team 2016). We found a similar approach could be applied whereby the tower operator or UAV pilot could communicate the location of a ferret observed using thermal-infrared cameras in real-time to other personnel prepared to immediately navigate to the observed ferret and conduct those additional steps typically used to capture and identify individuals. In this manner, thermal-infrared cameras could be used in conjunction with spotlight surveys to complement typical monitoring effort for this Endangered species.

Thermal-infrared cameras mounted to a tower or UAV may also provide a complementary survey technique that lessens the physical, light, and sound disturbances to the landscape produced during survey sessions. Both the tower and UAV-based surveys create virtually zero physical disturbance to the soil and vegetation within the grassland ecosystems where ferrets typically occur. Aside from the small lights equipped to UAVs used to maintain visual-line-of-sight between the pilot and the UAV, thermal-infrared cameras mounted to towers or UAVs do not emit substantial sources of light during nighttime surveys. While audible sound is produced by the rotation of the propellors during UAV flight, thermal-infrared cameras mounted to a tower produce almost no noise while in operation. Contrastingly, traditional methods that require repeated off-road vehicular use have the potential to disturb ground-nesting birds especially during spring surveys by increasing stress, reducing cover, and impacting predation (Dion et al. 2000, Conkling et al. 2015, Scholten et al. 2019) or promote the spread of invasive plants (Mack 2011, Scholtz & Twidwell 2022). Similarly, high-powered, long-ranging spotlights and vehicle headlights, as well as sounds emitted by motor vehicles, produce substantial light and sound disturbances during spotlight-based surveys. Ferrets have been found to decrease aboveground activity or increase movement to avoid these light and sound disturbances (Campbell et al. 1984, Biggins et al. 2006). Additional research on how varying levels of disturbances produced by different survey techniques impact grassland ecosystems, ferret behaviors, and detection rates could be important to future efforts to develop and improve survey methodologies.

Another potential benefit of using thermal-infrared cameras as described here is related to the detection of ferrets or other nocturnal wildlife based on heat signatures as opposed to spotlights during nighttime surveys. Spotlight surveys for ferrets often are aided by detection of eyeshine (Jachowski et al. 2010, Eads et al. 2012), whereas thermal-infrared cameras detect heat signatures emitted over the entire body of the animal (Burke et al. 2019). This attribute of thermal-infrared cameras therefore would allow for the detection of wildlife that may not be facing the surveyor or that may be partially hidden behind visual obstacles (i.e. vegetation, terrain) which would otherwise remain undetected if relying on spotlight surveys alone (McGregor et al. 2021). By elevating the thermal-infrared camera either by mounting to a tower or UAV, this feature may further benefit detections of ferrets by reducing the likelihood of visual obstacles between the camera and the ferret, especially in a grassland ecosystem where vegetation height is typically relatively short.

The evidence provided here that thermal-infrared cameras can detect ferrets offers the opportunity to explore how these emergent technologies might be further advanced to complement traditional survey methods. For example, investigation into optimizing the timing of thermal-infrared camera surveys related to environmental temperatures or flight speeds at which UAVs equipped with thermal-infrared cameras are operated may help to further improve detection rates (McGregor et al. 2021, Whitworth et al. 2022). Likewise, combining thermal-infrared imagery with other emerging technologies, such as the integration of artificial intelligence and machine learning, may streamline survey efforts by automating the detection of ferrets or other species of interest present on the landscape (Santangeli et al. 2020). A comparison of the cost-effectiveness of using thermal-infrared cameras and spotlight-based methods for detecting ferrets, or other similar species, could also be beneficial to managers and conservationists interested in these survey techniques. However, we note that such an evaluation could be a challenge to calculate given the high variability in personnel cost (i.e. varying salaries of paid employees versus volunteers), rapidly changing equipment costs for thermal-infrared cameras and UAVs including options to purchase or rent, evolving legal regulations associated with UAV use that vary by jurisdiction and organization, and differences in site-specific characteristics that may influence the effectiveness of any one technique.

In summary, this evaluation found that thermal-infrared cameras mounted to either a stationary tower or UAV can effectively detect ferrets during nighttime searches. Incorporating these survey methods into monitoring efforts may benefit ferret recovery and the conservation of grassland ecosystems at large by providing an effective means to obtain important detections of this Endangered species while creating less disturbance to the landscape and wildlife, while also alleviating potential navigation challenges associated with ground-based survey methods. Additional advancements in camera technologies as well as automated detections are expected to further the value of this detection technique for ferrets. These findings highlight the importance of routinely evaluating how emergent technologies can complement traditional survey methods and benefit conservation and recovery efforts for Endangered species.

Conflict of interest. Two of the authors on this manuscript are currently or were previously affiliated with commercial businesses that provide thermal camera and UAV services.

Acknowledgements. Thank you to the Fort Belknap Indian Community for their dedication to the conservation of the black-footed ferret and their permission to conduct this important research on their tribal lands. Thank you to Bureau of Indian Affairs Endangered Species Program and to Jackery, Inc. for funding portions of this research. We thank Vision Aerial and Blue Sky Drone for their assistance in acquiring the unmanned aerial vehicle and camera platforms used in this project. Thank you to all volunteers, including students from Aaniiih Nakoda College, who assisted with survey efforts. Finally, thank you to the US Fish and Wildlife Service for their continued support of our research on black-footed ferrets.

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Editorial responsibility: Alexandros A. Karamanlidis, Thessaloniki, Greece
Reviewed by: 3 anonymous referees
Submitted: July 18, 2024; Accepted: December 19, 2024
Proofs received from author(s): March 2, 2025