ASSESSING UNMANNED AERIAL VEHICLES EQUIPPED WITH THERMAL INFRARED TO LOCATE AND CAPTURE WHITE-TAILED DEER FAWNS

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SUMMARY OF FINDINGS

Drones are growing in popularity and are used to locate individual animals, estimate populations, and monitor species such as rhinoceros, penguins, marine mammals, and chimpanzees. However, previous research has not used drones to locate individual wildlife with the intent of capturing them. Our goal was to assess the efficacy of using drones to locate and capture neonatal white-tailed deer (*Odocoileus virginianus*). During May-June 2019, we used a drone with a thermal-infrared and Red-Blue-Green (RGB) camera to locate and confirm fawn thermal signatures in Wildlife Management Areas in Minnesota's southern farmland region. We identified 43 fawn and 117 adult deer heat signatures. We flew the drone for 47.3 hours covering approximately 792 hectares, which averaged 16.7 hectares per hour. We used 10 people to work 201.5 person-hours and spent 4.7 person-hours to locate each fawn. Flights were most efficient when flown at 6–7 m/s and at 60 m altitude; however, diurnal use of drones made identifying thermal fawn signatures difficult as the sun quickly heated vegetation reducing the temperature differential between vegetation and fawn signatures. In comparison to other common capture methods such as vaginal implant transmitters, ground searches, or doe behavior, using drones to locate fawns required up to 3.1 times less person-hours. We found this to be an efficient method to locate and capture fawns in open habitats in comparison to other capture methods, but recommend flying overnight or in cloudy conditions to avoid false positives.

INTRODUCTION

Neonatal survival is generally the most variable demographic parameter affecting population growth in ungulates (Gaillard et al. 2000). Understanding neonatal survival provides managers important information affecting recruitment and facilitates proactive management by identifying poor recruitment classes. Fawn survival rates and cause-specific mortality, particularly during the first hunting season and winter, are largely unknown or are outdated in Minnesota (Brinkman et al. 2004, Grovenburg et al. 2011) but are used in the Minnesota Department of Natural Resources (MNDNR) annual deer population model (Michel 2019). Using outdated vital rate information directly impacts model reliability which can affect subsequent management decisions for white-tailed deer (*Odocoileus virginianus*) in Minnesota (Michel 2019). However, a major logistical challenge and financial constraint associated with establishing and subsequently monitoring juvenile survival rates is locating and marking young ungulates (White et al. 1972, Carstensen et al. 2003). If fawns can be located efficiently, marking and collaring requires minimal physical restraint and no chemical immobilation or capture traps (e.g., netted-cage traps, drop nets).

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The most common neonatal fawn capture method in farmland regions (areas with intensive row-crop agriculture) is conducting opportunistic ground searches. Strategies include systematic searches through suspected fawn rearing habitat or monitoring doe behavior as an indicator of fawn presence nearby (Downing and McGinnes 1969, Huegel et al. 1985, Carstensen et al. 2003, Grovenburg et al. 2011). Previous capture methods have required numerous personnel, coordination of large search groups, and intensive searching effort. These studies also reported significant time investments for locating fawns [e.g., 8–10 hours/fawn captured via ground searches in Michigan (Pusateri 2003); range of 5–214 hours/fawn, depending on habitat, using doe behavior (White et al. 1972, Carstensen et al. 2003, Huegel et al. 1985)].

Using vaginal implant transmitters (VITs) is generally a more efficient means of capturing fawns compared to other methods. For example, capture success rates of fawns located from VITs implanted in dams was much greater (89% versus 15%) than using doe behavior to detect fawn presence. This increased efficiency reduced capture effort by up to 3.5 times that of using doe behavior (Carstensen et al. 2003). Similarly, Bishop et al. (2007) found capture success of mule deer (*O. hemionus*) fawns increased 57% when using VIT's compared to using doe behavior. However, using VITs requires capturing adult females, which increases associated costs and may also may result in unnecessary stress and capture related mortality of adult females during capture. As a result, these techniques may be less efficient and cost effective than using ground searches.

Using thermal infrared (TIR) cameras can be efficient for identifying and subsequently capturing wildlife. One of the first wildlife studies to use TIR devices identified a polar bear (*Ursus maritimus*) and its tracks (Brooks 1972). Thermal imaging has also been used to estimate populations of ungulate species such as moose (*Alces alces*; Millette et al. 2011), bison (*Bison bison;* Chrétien et al. 2015), elk (*Cervus canadensis;* Chrétien et al. 2015), and white-tailed deer (Croon et al. 1968, Wiggers and Beckerman 1993, Haroldson et al. 2003). Ditchkoff et al. (2005*a*) also used TIR cameras mounted on the back of a 4-wheel drive vehicle to locate fawns. They conducted searches overnight to maximize the heat differential between fawn signatures and surrounding area. This technique required 3.3 person-hours per fawn encounter, 9.4 person-hours per fawn captured, and only 2–3 personnel to conduct the fieldwork. Although vehicle mounted TIR cameras are more effective than previous search methods, they are restricted to roads which ungulates typically avoid (Ward et al. 2004, Long et al. 2010, Anderson et al. 2013).

Unmanned aerial systems (UAS or drone) used for civil applications offers new opportunities for wildlife managers (Shahbazi et al. 2014, Whitehead and Hugenholtz 2014). Drones have been used for surveys of marine mammals (Hodgson et al. 2013, Goebel et al. 2015), to monitor rhinoceros (*Diceros bicornis and Ceratotherium simum*) poaching (Mulero-Pázmány et al. 2014), identify chimpanzee (*Pan spp.*) nests (Van Andel et al. 2015), and estimate colony size of chinstrap penguins (*Pygoscelis antarcticus*, Goebel et al. 2015). Recent studies show drones provide many advantages over traditional manned aerial surveys including lower disturbance, higher quality images, and lower flight altitudes, and they are safer for pilots and biologists (Jones et al. 2006, Linchant et al. 2015, Christie et al. 2016). A drone is also not spatially limited and has improved detection compared to ground-based TIR cameras because the aerial view avoids vertical obstruction from herbaceous ground cover. Using drones to locate fawns could reduce the primary cost associated with capture efforts (Kissell and Nimmo 2011, Chrétien et al. 2015, 2016, Linchant et al. 2015, Christie et al. 2016, Witczuk et al. 2018). Recently, drones with TIR detected and counted white-tailed deer in Quebec, Canada (Chrétien et al. 2016), while another study found drones with TIR provided accurate population estimates at a captive white-tailed deer facililty (Beaver et al. 2020). A drone with TIR was also used to detect roe deer

(*Capreolus capreolus*) fawns in pastures to avoid them being killed by mowing machines (Israel 2011). However, no published research has identified or evaluated drone use to efficiently locate fawns or adult ungulates with the intent of capturing them.

Although the use of drone and TIR technology in wildlife research is increasing rapidly, efficacy of these technologies for locating fawns as part of capture efforts is unknown; thus, a feasibility study is needed prior to implementing these tools in large-scale research projects.

OBJECTIVES

1. Evaluate the ability of drones equipped with TIR technology to locate fawns.
2. Compare search rate efficiency to other methods.

METHODS

Study Site

We collected data from May to June 2019 across 4 deer permit areas (252, 253, 296, and 299) covering 7,219 square kilometers in south central Minnesota, USA (Figure 1). Our study area was located in the North Central Glaciated Plains system (MNDNR 2019). Row crop agriculture (largely corn and soybeans) was the most abundant cover type accounting for 71% of the area, with grasslands (12%), developed (7%), wetlands (5%), forest (3%), and open water (2%) cover types encompassing the remaining area (Rampi et al. 2016). Within the study area, we located fawns at publically owned Wildlife Management Areas (WMAs). These WMAs consisted largely of wetlands (37%) and grasslands (34%), but also agriculture (corn; 12%), open water (9%), and forest (7%; MNDNR 2009). Most common graminoids included smooth brome (*Bromus inermis*), reed canary grass (*Phalaris arundinacea*), little bluestem (*Schizachyrium scoparium*), and Indian grass (*Sorghastrum nutans*). Common forbs were gray goldenrod (*Solidago nemoralis*), sweet clover (*Melilotus albus*), and Canada goldenrod (*Solidago canadensis).* Eighty-two WMAs were located within or immediately adjacent to our study area (Figure 1) and available for locating deer fawns. We determined suitability of these WMAs by analyzing aerial photos of each site for large parcels of grassland or lightly forested cover (cover types heavily used by fawns in agricultural landscapes; Grovenburg et al. 2010). We also visited 55 of the sites to confirm aerial imagery and further evaluate the habitat. We determined 53 WMAs contained suitable deer fawning habitat. Unsuitable areas were largely open water and emergent wetlands.

Data Collection

We contracted with a drone company (PAAP Drone LLC, Apple Valley, MN, USA) to create flight paths (Figure 2) and fly their drone at each of our sites. The drone contractor created 2 flight paths for each WMA at 45 and 60 m altitude with a 10% overlap. For flights, we used a DJI Matrice 210v2 RTK UAV with a thermal (DJI Zenmuse XT-R: 640x480 13mm, 30 Hz Advanced Radiometric Thermal Camera) and Red-Green-Blue (RGB) camera (DJI Zenmuse Z30 Zoom Camera). We selected this UAS because it allows 2 camera mounts and the ability to interchange cameras while in flight. We used the TIR camera to locate thermal signatures and the RGB camera to confirm fawns. We connected the ground control system to a 50 cm screen (via HDMI) to allow more observers to monitor thermal signatures.

We recorded number of crew members, number of batteries used, temperature, wind speed, cloud cover, and precipitation at each WMA. Pilots flew drones through the preprogrammed flight path until we detected a suspected fawn. The drone pilot would then pause the preprogrammed flight path and manually direct the drone over the suspected fawn. Next, the drone pilot switched to the RGB camera and confirmed identification by modifying the zoom–

scale of the camera rather than adjusting flight altitude of the drone. This procedure minimized auditory stress, disturbance, and stress-flight behavior of the fawn. The drone contractor recorded georeferenced video footage and photo-documented fawning site characteristics. We recorded the following for each fawn detection: number of fawns, time, activity (e.g., lying, standing, moving), habitat type, doe presence, thermal obstruction (from vegetation), and the location (e.g., latitude and longitude). We also recorded similar information for other species confirmed within the WMAs.

We found diurnal conditions rapidly reduced our ability to locate thermal signatures and therefore began performing early morning (02:00 – 06:00) flights. In diurnal and sunny conditions, groundcover quickly illuminated with the TIR camera and caused many false positives. We could not confirm a suspected heat signature as a fawn during nighttime conditions (e.g., no/low sunlight for RGB camera); therefore, we recorded the coordinates of the heat signature and attempted to confirm via drone after sunrise or with a ground search. We were unable to confirm a suspected fawn in some cases, potentially because its mother may have moved the suspected fawn.

RESULTS

We conducted drone flights for 10 days between 28 May 2019 and 11 June 2019 on 19 WMAs. We flew for 47.3 hours and covered 791.7 hectares. We identified 43 suspected fawn heat signatures and confirmed 29 heat signatures using the RGB camera, ground visualization, or the presence of a doe and/or confirmed twin (Figure 3). We identified 14 fawns before sunrise but were unable to confirm 10 with the RGB camera after sunrise. However, we were confident these unconfirmed heat signatures were fawns because of their thermal signature size.

We used 10 people to work 201.5 person-hours, with a mean crew size of 4 people. We required a mean of 4.7 person-hours to locate each fawn. The drone covered a mean of 18.4 hectares for each fawn. We also attempted to improve our efficiency by increasing our speed from 4–5 m/s and 45-meter altitude (Eff 1) to 6–7 m/s and 60–meter altitude (Eff 2) Eff 1 required 5.8 person-hours per fawn, while Eff 2 only required 2.2 person-hours per fawn (264% increase; Table 1).

We located 39 fawns (91%) in grasslands and the remaining 4 (9%) in woodlands. We found all fawns bedded (Figure 3) and observed no physical responses from the drone. Fawn obstruction (of heat signature) from vegetation was 27.5 ± 22.0 (SD) % (range = 0–90%, n = 14). The doe was present with the fawn in 45% (17/38) of observations, with the remaining 5 fawns' doe presence unknown.

We identified and confirmed heat signatures of other wildlife including coyotes (*Canis latrans*) with pups, raccoons (*Procyon lotor*), muskrats (*Ondatra zibethicus*), mallards (*Anas platyrhynchos*), ring-necked pheasants (*Phasianus colchicus),* and many small mammals and other birds. We also recorded 63 adult white-tailed deer groups (117 individuals). We found thermal signatures of coyotes and adult deer were approximately 2.7 times larger than neonatal fawns. We observed most species in grasslands (82.6%), followed by woodlands (9.3%), wetlands (3.5%), cropland (2.3%), and other (2.3%). We observed animals most often found lying (41.9%), followed by moving (34.9%), and standing (23.2%). We also found 68.6% of animals did not physically respond to the drone by altering their behavior.

DISCUSSION

We flew at Eff 1 (4–5 m/s; 45 m) for the first several days to quantify the performance of this search method. After increasing confidence in our ability to detect fawns, we moved to Eff 2 (6–

7 m/s; 60 m) to assess whether flying at these metrics allowed us to locate fawns more efficiently. The height change increased the search swath by approximately 25%, allowing us to cover substantially more area. After we increased the speed and height, we covered approximately 53% more hectares per hour and lowered our person-hours per fawn by 264%. We ran a simulation with Eff 2 parameters with flight time kept constant and found we would be able to fly 1,352 hectares and locate 86 fawns.

Using drones equipped with TIR is more efficient than using TIR with a vehicle because we are not limited to searching near roads, which deer avoid (Ward et al. 2004, Long et al. 2010, Anderson et al. 2013). Our current drone efficiencies (Eff 1 and Eff 2) also included issues with software, sunlight, canopy cover, battery life, and confirmation of fawns. If these issues can be resolved, we could further increase efficiency. The drone with TIR method was more effective at locating fawns versus ground searches because ground searches require extensive personnel effort and likely have a lower fawn detection rate compared to our method. VITs are also less efficient because they require adult capture and ground searches to locate the fawn within a given area. When a VIT is expelled they are notified and then the capture team is launched, whereas we located and captured fawns instantaneously.

Vaginal Implant Transmitters are the most costly search method because they require adult capture to GPS-collar and insert a transmitter into the vaginal canal (Carstensen et al. 2003). Capturing and GPS-collaring of adult females is unwarranted unless specific female objectives are stated. The cost of ground searches is difficult to estimate because the unknown number of individuals required to conduct ground searches and the extensive coordination efforts pre-fieldwork conducted by personnel. However, ground searches do not require a drone contractor or expensive drone equipment to conduct the searches. The largest cost for the drone method was the drone contractor costs. We are currently not allowed to purchase drones within the MNDNR for specific projects and are required to contract for the work. If other studies have the capability to purchase their own drone and conduct flights, the method would be more cost effective than ground searches, especially after multiple years of use. Owning a drone also allows for more flying flexibility. For example, we conducted flights under poor conditions because we had designated flight dates with our contractor. We could have flown across a wider range of dates if we were not limited by these dates.

We experienced several technical difficulties while conducting flights. For example, the gimbal on the drone, which facilitates independent movement of the RGB and TIR camera, ceased function frequently. This required us to return the drone to the ground for a manual reset. We found the failed gimbal function was caused by a flaw in the software update and was resolved after completion of our study. Drone technology is expanding quickly; troubleshooting software and other potential issues should be considered while determining the best search method for your study area. Our drone contractor recommended not upgrading drones, cameras, or software shortly before the field season to avoid new issues with software updates (Steve Fines, personal communication). We also experienced difficulty switching between the TIR and RGB cameras to quickly confirm a suspected fawn's thermal signature. The drone has 2 gimbals: 1 for the TIR camera and the other for the RGB camera, but the direction between the 2 cameras was not perfectly aligned. After we located a thermal signature, we orientated the signature directly below the drone and then switched to the RGB camera to confirm the suspected fawn signature. Because of the alignment problem, we needed to slowly move the drone back and forth and modify the zoom–scale to search for the suspected fawn. This slight difference between cameras caused considerable loss of time confirming fawns. A new camera has since been developed with both TIR and RGB in 1 unit allowing for perfect alignment. This camera also has a split-screen feature to view both cameras simultaneously and allow for quicker confirmations. Battery life was also an issue with maximum battery life of the DJI Matrice 210v2 RTK drone lasting approximately 38 minutes. Because we used 2 cameras (RGB and TIR), our battery life was reduced to approximately 25 minutes. A sufficient number of batteries and a charging source (e.g., generator) is necessary for use of drones for wildlife capture. The largest difficulty we encountered was limited flight time during daylight hours. We found the sun quickly heated the ground and washed out our ability to locate thermal fawn signatures. Detection of thermal signatures was adequate immediately after sunrise because the sun was still low and not able to penetrate the ground. However, fawn detection continually decreased until we were unable to locate thermal signatures about 3 hours after sunrise. We resolved this issue by moving our operation time to early morning (03:00 to 09:00). A part 107 federal waiver is required to fly a drone at nighttime. This waiver allows drone pilots to deviate from certain rules under part 107 by demonstrating the drone can still fly safely using alternative methods (U.S. Department of Transportation 2019). We then attempted to confirm fawns via ground or with the drone after sunrise but found some signatures were no longer present. The doe may have nursed the fawn and then moved the fawn to a new location. We plan to confirm fawns this upcoming field season by night vision technology on the drone or confirming via walking in prior to sunrise.

Canopy cover also caused reduced ground visibility because the TIR was unable to penetrate through the canopy. We also found trees held residual heat for an extended period of time from the previous day and quickly heated up in sunny conditions. Locating fawn signatures was possible in lightly wooded areas, but difficult in forested habitats. Researchers looking to use this method in forested areas may have less success.

We flew the first 7 days of drone flights at a slower speed and lower height to identify all thermal signatures and learn signature size of different species. We determined a fawn's thermal signature size and shape was unique and easy to differentiate from other signatures. We found thermal signatures of coyotes and adult deer were much larger than neonatal fawns. Fawns also curled up when bedded making their shape distinctive from other signatures. Raccoons were similar in size to fawns, but few were located during the drone flights. Fritzell (1978) found raccoons typically used developed, wooded, and wetland areas, whereas we conducted most of our flights in grasslands. We also identified raccoons did not curl their heads into their body to form a circular signature similar to fawns. We did, however, note several fawn-like signatures that were actually holes created by coyotes or small mammals that quickly heated with the sun.

We found fawn disturbance to be low with all fawns remaining bedded and only a few lifting their head in response to the drone. To further minimize disturbance, we increased the drone height from 45 m to 60 m. Linchant et al. (2015*b*) reviewed several drone studies and found no disturbances reported during drone flights. Although not directly related, Christie et al. (2016) showed lower disturbances compared to other aerial methods; therefore, drones may be an advantageous method for minimizing disturbance of wildlife in general.

We found drones have applicability with not only large, but also smaller mammals. We observed and confirmed a multitude of wildlife species during our flights. Although we were able to detect the thermal signatures of passerine species, we did not record them because they were not comparable to a fawn signature (i.e., there was little chance of misidentifying the thermal signature of a passerine as a fawn's thermal signature). We did detect a mallard and her ducklings at 45 m height. Another study used drones to search for fawns during mowing operations and located foxes, rabbits, and small mammals at 30 – 40 m altitude (Israel 2011). Furthermore, drones show immense promise in the future of wildlife detection and estimation, and provide a higher search efficiency compared to previous methods.

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Table 1. List of methods used to locate and capture deer fawns (*Odocoileus* spp.) across various studies. Also shown is the year of the study, sample size (N), and effort (person-hours) from each study.

Location/Capture Method	Year	N	Effort	Study
Drone w/ Thermal Imaging (Eff. 1)	2019	33	5.8	Obermoller et al. (this study)
Drone w/ Thermal Imaging (Eff. 2)	2019	10	2.2	Obermoller et al. (this study)
Vaginal Implant Transmitter	2003 - 2004	83	7 - 16	Bishop et al. 2007
Vaginal Implant Transmitter	2001	20	60	Carstensen et al. 2003
Doe Behavior	1997 - 1999	25	145 - 214	Carstensen et al. 2003
Doe Behavior	1980 -1983	58	14.5 - 43.8	Huegel et al. 1985
Vehicle w/ Thermal Imaging	2004	26	3.3 - 9.4	Ditchkoff et al. 2005
Ground Searching	1994 - 1996	35	30.6	Ballard et al. 1998

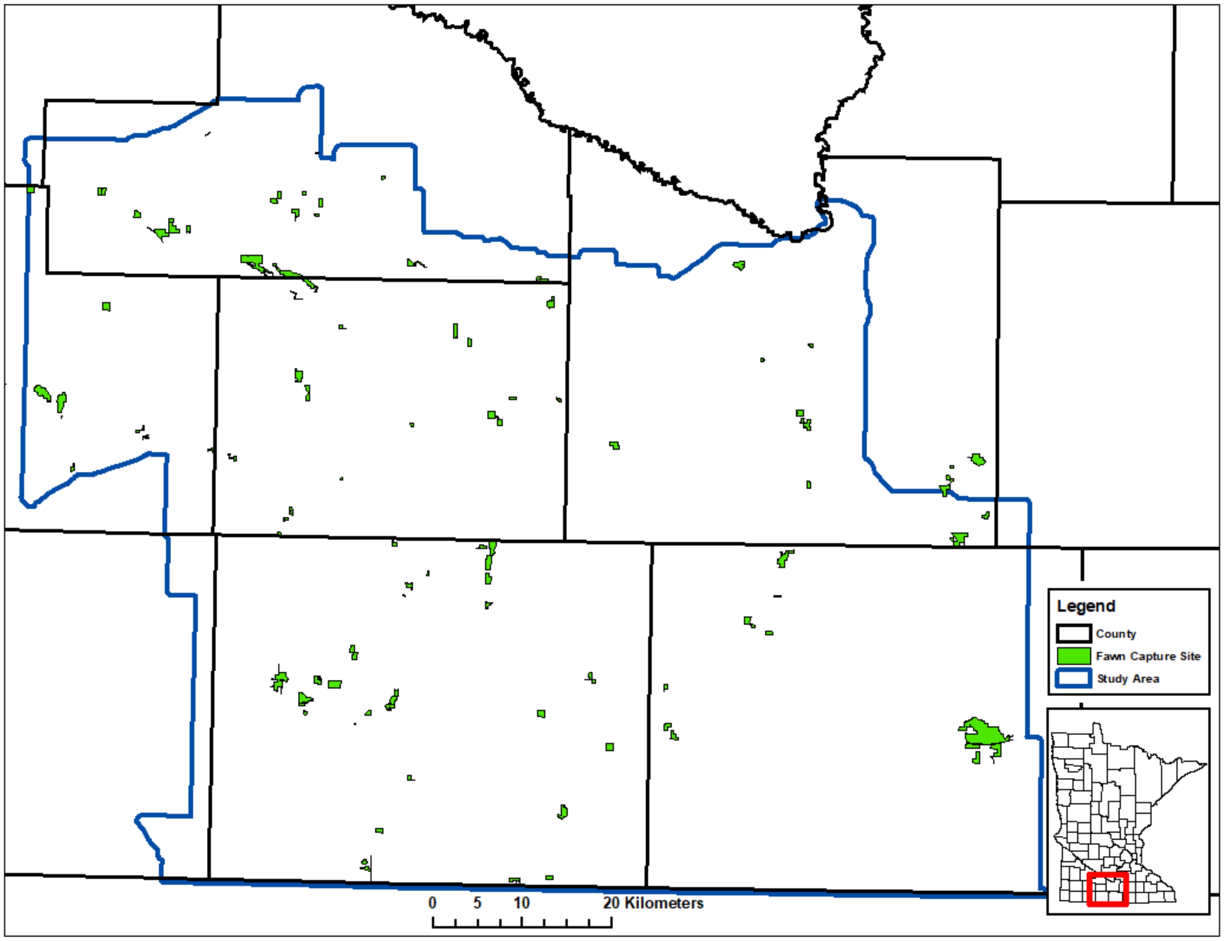

Figure 1. Study area including location of Wildlife Management Areas (green polygons) where white-tailed deer fawns were located and captured in south central Minnesota, USA from May to June 2019.

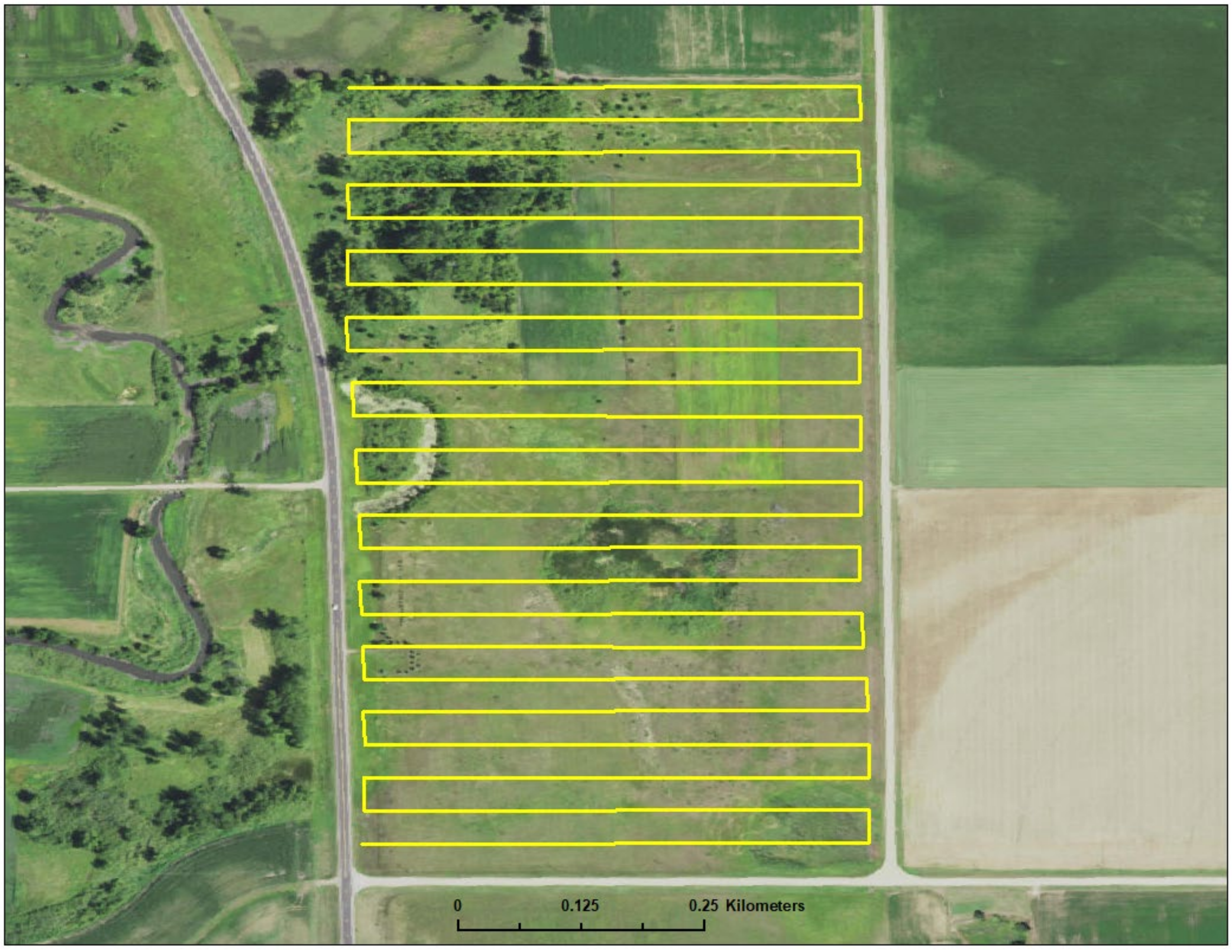

Figure 2. Flight path (yellow polylines) of the drone used to search for white-tailed deer fawns at Groebner Wildlife Management Area in south central Minnesota, USA, June 2019. This flight covered 32 hectares over 96 minutes with a 45-meter flight swath.

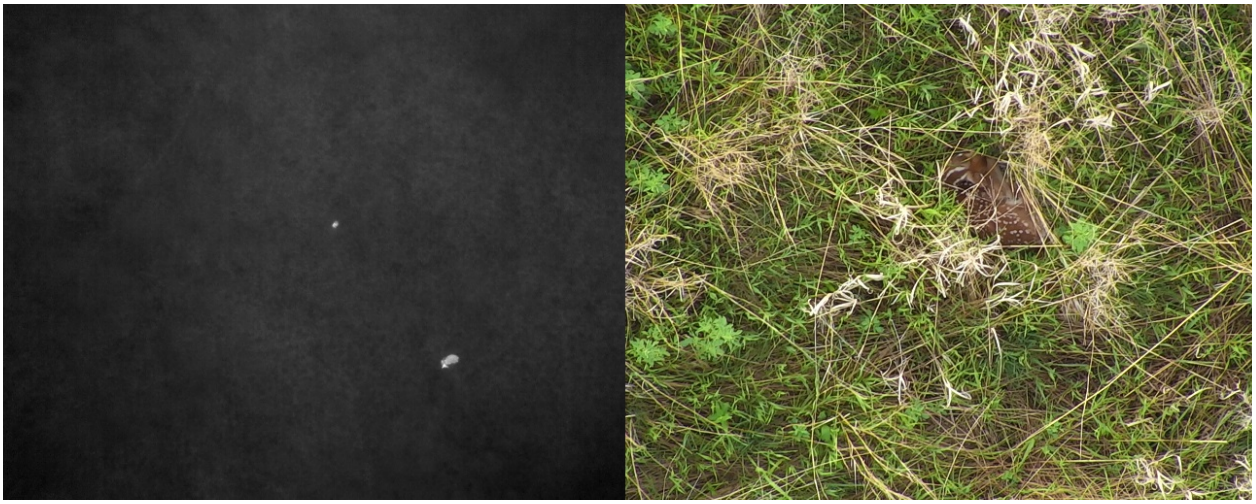

Figure 3. Thermal infrared image from a drone of a white-tailed deer fawn and her dam (left) and a zoomed-in image of the same fawn bedded in grass (right) in south central Minnesota, USA, June 2019.