ASSESSING USE OF THERMAL INFRARED DRONES TO LOCATE AND CAPTURE WHITE-TAILED DEER FAWNS FOR MONITORING OF SURVIVAL AND CAUSES OF MORTALITY

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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 capture. Our goal was to assess the efficacy of using drones to locate and capture neonatal white-tailed deer (*Odocoileus virginianus*). During May–June 2021 and May 2022, we used a drone with a thermal-infrared and Red-Blue-Green (RGB) camera to locate and capture fawns in Wildlife Management Areas in Minnesota's southern farmland region. We located and captured 75 and 82 neonatal fawns in 2021 and 2022, respectively. We flew the drone for 46.7 hours and covered 2,072.6 hectares (44.4 hectares per hour) in 2021, whereas we flew for 43.4 hours and 2,620.1 hectares (49.2 hectares per hour) in 2022. Our effort was 3.1 and 2.4 person-hours to capture each fawn in 2021 and 2022, respectively. In comparison to other common capture methods such as vaginal implant transmitters, ground searches, or doe behavior, using drones to locate and capture fawns was much more efficient and required fewer personnel. Although we found drones to be an efficient method, we 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 on annual recruitment and can help facilitate proactive management. White-tailed deer (*Odocoileus virginianus*) fawn survival rates, particularly during the first hunting season and winter, are largely unknown or are outdated in Minnesota (Brinkman et al. 2004, Grovenburg et al. 2011) but are used in the Minnesota Department of Natural Resources (MNDNR) annual deer population model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 and Giudice 2022). Using outdated vital rate information directly impacts model reliability which can affect subsequent management decisions for white-tailed deer in Minnesota (Michel and Giudice 2022). However, a major logistical challenge and financial constraint associated with 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 immobilization or capture traps (e.g., netted-cage traps, drop nets).

The most common neonatal fawn capture method in grassland regions 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 required numerous personnel, coordination of large search groups, and intensive search efforts. Pusateri (2003) reported 8-10 person-hours per fawn captured via ground searches in Michigan, compared to 5-214 person-hours per fawn 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 (88% versus 15%) than using doe behavior to detect fawn presence (Carstensen et al. 2013). 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 VITs compared to using doe behavior. However, using VITs requires capturing adult females, which increases associated costs and can also result in unnecessary stress of adult females during capture.

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 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) 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).

Drones used for civil applications offer new opportunities for wildlife managers (Shahbazi et al. 2014, Whitehead and Hugenholtz 2014). Recent studies show drones provide many advantages over traditional manned aerial surveys including lower disturbance and flight altitudes, higher quality images, and improved safety for pilots and biologists (Jones et al. 2006, Linchant et al. 2015, Christie et al. 2016). A TIR-equipped drone also has improved detection compared to ground-based TIR cameras because the aerial view minimizes obstruction from herbaceous ground cover, reducing search effort costs (Kissell and Nimmo 2011, Chrétien et al. 2015, 2016, Linchant et al. 2015, Christie et al. 2016, Witczuk et al. 2018). Recently, TIR-equipped drones were used to detect and count white-tailed deer in Quebec, Canada (Chrétien et al. 2016) and captive white-tailed deer in Alabama (Beaver et al. 2020). Thermal-infrared equipped drones were also used to detect roe deer (*Capreolus capreolus*) fawns in pastures to minimize mowing mortality (Israel 2011).

Neonatal fawn survival is affected by several factors, but predation is often the leading cause of mortality (Carstensen et al. 2009, Grovenburg et al. 2012, Severud et al. 2019). Coyote (*Canis latrans*) predation had the largest impact on fawn survival in the Northern Great Plains and South Dakota (Grovenburg et al. 2012). Additionally, fawn survival in south central Minnesota was last estimated almost 20 years ago and coyote track survey indices have increased 252% from 2000 to 2020 (J. Erb, MNDNR, pers. comm.). Therefore, the impact of coyote predation on fawn survival is outdated and has likely changed since it was last estimated. Other studies have reported additional sources of mortality including hunting, hypothermia, starvation, and vehicle collisions, and these may have important implications for population dynamics (Pojar and Bowden 2005, Burroughs et al. 2006, Kilgo et al. 2012).

Global Positioning System (GPS) collars are an essential tool to identify causes of mortality (Severud et al. 2015, Swanepoel et al. 2015) and also expand our understanding of animal movements (e.g., dispersals, migrations; (Nelson and Mech 1984, Purdon et al. 2018), resource use (Hebblewhite et al. 2005, Bista et al. 2023), behavior (Creel et al. 2008, Chimienti et al.

2021, Pokrovsky et al. 2021), and home range size (Nelson and Mech 1984, Körtner et al. 2015). The addition of expandable bands on GPS collars allows researchers to monitor animals with changing body size shortly after birth until important biological life events (e.g., dispersal, overwinter survival, recruitment; Gaillard et al. 1998, Severud et al. 2015, Gilbertson et al. 2022). Past design iterations for neonatal ungulates required heavy GPS packages to meet increased location fix rates, leading to premature band expansion via increased stress on the expandable bands (Obermoller et al. 2018). Poor collar designs (i.e., poor stitching strength and band material) can lead to a loss of data through censored animals (DelGiudice et al. 2002, Severud et al. 2019). Subsequently, we collaborated with researchers from the University of Georgia to test 3 expandable GPS collar models for their retention and influence on behavior of captive fawns (see Wesner et al. 2022 for details). We then used results from our pen study along with existing data from our 2019 pilot field study (Obermoller et al. 2020, Obermoller et al. 2021) to suggest design modifications to the collar companies. Our suggestions were for improved stitching patterns, smaller battery housings, improved weight distribution, and smaller band circumference. Although our pen study helped with initial assessment and refinement of collar designs, a critical next step is to field test these expandable GPS collars on wild neonatal fawns.

In 2019 and 2020, we conducted a feasibility study using TIR drones and determined this method was an efficient technique to locate fawns (see Obermoller et al. 2021) but using this technology for capture efforts was still largely unknown. Thus, we continued our research to determine the feasibility of using TIR drones to assist with capturing in 2021 and 2022. We acknowledge comparisons among fawn search and capture techniques can be confounded by a variety of factors; however, the intent of our research was to provide information about the efficacy, benefits, and challenges associated with the use of TIR drones to locate neonatal white-tailed deer for capture. Additionally, we evaluated expandable GPS collars by determining retention rates of 2021 and 2022 band designs and assessing the GPS collar function (e.g., fix success rate, mean linear error) in grassland and forested cover types. Fawn captures can be logistically and financially prohibitive yet are necessary to collect the data needed for a variety of research and monitoring objectives (e.g., survival rates, causes of mortality, habitat use and selection).

OBJECTIVES

1. Evaluate the efficiency of using TIR-equipped drones to locate neonates for capture.
2. Validate performance of Vectronic GPS radiocollars on free-ranging white-tailed deer fawns.
3. Identify cost-effective approaches for long-term and large-scale monitoring of fawn survival and recruitment in Minnesota's farmland regions.

METHODS

Study Site

Our 7,219 km^2 study area consists of 4 deer permit areas (DPAs; 252, 253, 296, 299) in south central Minnesota, USA (Figure 1). Recently, deer densities have averaged 8–21 deer per square mile across the 4 DPAs (Michel and Giudice 2022). Row crop agriculture, largely corn (*Zea mays*) and soybeans (*Glycine max*), are the most abundant cover type accounting for 71% of the area, with grasslands (12%), urban/developed (7%), wetlands (5%), forest (3%), and open water (2%) encompassing the remaining area (Rampi et al. 2016). Within the study area, we focused our drone flights on Wildlife Management Areas (WMAs) maintained by the MNDNR. Study WMAs consisted largely of wetlands (37%) and grasslands (34%), but also agriculture (corn food plots; 12%), open water (9%), and forest (7%; MNDNR 2009). The most common graminoids included smooth brome (*Bromus inermis*), reed canary grass (*Phalaris arundinacea*), big bluestem (*Andropogon gerardii*), switchgrass (*Panicum virgatum*), and Indian grass (*Sorghastrum nutans*). Common forbs included goldenrod (*Solidago spp.),* sweet clover (*Melilotus spp.*), aster (*Symphyotrichum spp.*), and milkweed (*Asclepias spp*.).

Data Collection

We contracted with a drone company (Fines Aerial Imaging, St. Cloud, MN, USA) to create flight paths (Figure 2) and fly their drone at each of our sites in 2021 and 2022. The drone contractor created a flight path for each WMA at 60-m altitude with a 10% overlap. We used a DJI Matrice 300 RTK drone with dual thermal-infrared (DJI H20T: 640 x 512 pixels 13.5 mm focal length, 30 Hz Advanced Radiometric Thermal Camera) and Red-Green-Blue (RGB) camera (DJI H20T: 1920 x 1080 pixels, 6.8-120 mm focal length). The drone had a single housing with both thermal and zoom camera capabilities and therefore allowed for seamless transitions between cameras while in flight. We used the TIR camera to locate thermal signatures and the RGB camera to confirm fawns (Figure 3). We connected the ground control system to a 50-cm screen (via HDMI) to allow more observers to monitor thermal signatures.

Pilots flew drones through the preprogrammed flight path until we detected a suspected fawn. The pilot would then pause the preprogrammed flight path and manually direct the drone over the suspected fawn. Next, the 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 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 found diurnal conditions rapidly reduced our ability to locate thermal signatures and therefore began performing early morning (0200 – 0600) 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 fit Vectronic Vertex GPS radiocollars (with 3-axis accelerometers to identify body movement; Vectronic Aerospace GmbH, Berlin, Germany) to neonatal fawns to closely monitor survival, reduce our response time for mortality investigations, and increase our ability to confidently identify causes of mortality. We examined carcass characteristics to determine depredated versus scavenged and the predator type. We searched the immediate area for other evidence such as predator hair, tracks, or scat. We also collected scat and saliva swabs (swabbing predator bite wounds on fawns) to use in DNA analysis to assign specific causes of mortality to a specific predator species (Obermoller et al. 2019). If mortality cause was unknown and sufficient carcass remained, we delivered it to the University of Minnesota's Veterinary Diagnostics Laboratory (VDL) for necropsy. We calculated Kaplan-Meier survival using the KMsurv package in Program R (R Core Team 2022).

We also conducted a 1-week trial to assess the efficacy of the GPS package by estimating the mean linear error and fix-success of transmitting locations by habitat type starting on 16 July 2021. We placed 10 collars in 2 habitat types: grassland habitat (0% average canopy cover) and forested (deciduous) habitat (94% average canopy cover). We selected these habitats because they were frequently used by our GPS-collared neonates and provided an assessment of the collars' function in two vastly different cover types. We used a handheld GPS unit (Garmin GPSMAP 64s) to record an averaged location-fix until confidence reached 100% at the specific focal point for each cover type. We then placed a neonate GPS collar on the ground at the focal location to simulate a bedded fawn and reduce the effect behavior may have on collar error (Bowman et al. 2000). Next, we placed 4 neonate collars 5 m, 10 m, 15 m, and 20 m east of the focal location, respectively. Starting 5 m north of the focal location, we then placed another parallel row of 5 collars 5 m north of the first row. We then calculated the exact easting and northing coordinates for each collar from the focal location (Obermoller et al. 2018). Finally, we estimated the location error from the Euclidean distance between location-fixes and the exact location of each individual collar's location. We programmed the collars to send 1 location per hour during the week-long trial. We did not assess the location error of the collars in 2022 due to the GPS-collar technology being identical between years. We calculated the mean linear error for each collar and then compared error by cover type. We used a simple linear regression to compare mean Euclidean location error by cover type and collar ID.

RESULTS

2021

We conducted drone flights for 46.7 hours and covered 2,072.6 hectares (44.4 hectares per hour) at 17 WMAs. We worked 233.5 total person-hours with a mean crew size of 5 people and required a mean 3.1 person-hours to capture each fawn. We GPS-collared 75 fawns (38 males, 37 females); 73 fawns were located using the drone and 2 fawns were found opportunistically. Captured fawns were 5.3 ± 2.3 (SD) days old (range 0-11 days, n = 75) and weighed 4.5 ± 1.0 kg (range = 2.7-7.1 kg, n = 73). The hind leg length was 27.0 ± 1.6 cm (range = 21.1-30.2 cm, n = 74). We captured 76% (57) of fawns in grasslands, 15% (11) in wetlands, 5% (4) in forested habitats, 3% (2) in roadsides, and 1% (1) in standing crops. The doe was present for 28% of fawn captures. We documented 26 mortalities: 17 coyote kills, 5 health-related, 2 vehicle collisions, and 1 accident. The 1- and 3-month (summer) survival were 85.6% and 78.1%, respectively (Figure 4). The 6-month and 1-year survival were 71.8% and 66.2%, respectively.

We found retention issues with the expandable band for 23 of 73 (32%) collars by 1 year of age: 9 (40%) premature collar expansion, 7 (30%) caught on fences, and 7 (30%) with expandable bands breaking (Figures 5A-5D). The mean number of days the collars were retained was 150 days (±115, range = 2-359 days, n = 23). Collar retention was 88% at 3 months of age (spring/summer survival), declining to 59% (n = 28) at 1 year of age.

The mean linear location error of the GPS collars was 12.7 m (95% CL = 11.1, 14.4, range = 10-17 m, n = 10) in forested cover and 5.1 m (95% CL = 4.2, 5.9, range = 4-7 m, n = 10) in grassland cover. We found GPS location error was significantly different by cover type ($F_{1,18}$ = 85.6, p ≤0.001) and collar ID ($F_{3,16}$ = 40.4, p = 0.02).

2022

We conducted drone flights for 43.4 hours and covered 2,620.1 hectares (49.2 hectares per hour) at 21 WMAs. We worked 197.9 total person-hours with a mean crew size of 5 people and required a mean 2.4 person-hours to capture each fawn. We GPS-collared 82 fawns (49 males, 33 females); 81 fawns were located using the drone and 1 fawn was found opportunistically. Captured fawns were 3.3 ± 1.9 (SD) days old (range 0-10 days, n = 82) and weighed 4.3 ± 1.1 kg (range = 2.0-8.3 kg, n = 82). The hind leg length was 26.6 ± 1.8 cm (range = 21-31 cm, n = 82). We captured 54% (44) of fawns in grasslands, 28% (23) in wetlands, and 18% (15) in forested habitats. The doe was present for 32% of fawn captures. We documented 47 mortalities: 36 coyote kills, 4 health-related, 4 vehicle collisions, and 3 harvest-related. The 1-

and 3-month (summer) survival were 68.4% and 55.2.1%, respectively (Figure 4). The 6-month and 1-year survival were 47.3% and 31.4%, respectively.

We found retention issues with the expandable band for 22 of 81 (27%) collars with similar expandable band issues: 12 (55%) caught on fences, 8 (36%) expandable bands breaking, and 2 (9%) premature collar expansion (Figures 5A-5D). The mean number of days the collars were retained was 160 days (±94, range = 13-333 days, n = 22). Collar retention was 91% at 3 months of age (spring/summer survival), declining to 41% (n = 10) at 1 year of age.

DISCUSSION

We found using TIR-equipped drones was an effective method to locate and then capture neonatal fawns for GPS-collaring and subsequent survival monitoring. We also found our method was more efficient than using TIR with a vehicle because we were not limited to searching near roads, which deer avoid (Ward et al. 2004, Long et al. 2010, Anderson et al. 2013; Table 1). Additionally, ground searches require extensive personnel effort and likely have a lower fawn detection rate compared to our method. The cost of ground searches is difficult to estimate because of the unknown number of individuals required to conduct ground searches and the extensive pre-fieldwork coordination efforts conducted by personnel. Vaginal implant transmitters (VITs) are also less efficient because they require adult capture, followed by ground searches after parturition to locate the fawn within a given area (Table 1). When a VIT is expelled, personnel are notified and then a capture team is launched, whereas we located and captured fawns instantaneously. We acknowledge that we are capturing slightly older fawns compared to those captured via the use of VITs. Therefore, our survival estimates may be biased because mortalities occurring within the first days of life may be missed (Gilbert et al. 2014, Chitwood et al. 2017), although estimating fawn age and entering them into the survival analysis based on age will help reduce bias (Kautz et al. 2019). Additionally, VITs are the more costly search method because they require capture and collaring of adults and insertion of the VIT, all of which require more personnel, time, equipment, and supplies (Carstensen et al. 2003). Capturing and GPS-collaring of adult females is unwarranted unless specific female monitoring objectives are stated.

The greatest challenge we encountered was thermal loading to the environment during diurnal hours. We found the sun quickly heated the ground and reduced the temperature differential between the vegetation and fawn thermal signatures (Israel 2011, Chrétien et al. 2016, Beaver et al. 2020). Detection of thermal signatures was adequate immediately after sunrise because the sun was still low on the horizon. However, our ability to detect fawns deteriorated as the sun rose and detection of thermal signatures was no longer possible about 3 hours after sunrise. On overcast days, we were able to detect fawns throughout the day. We therefore moved our operation start times to early morning hours (0200 to 0900), which resolved the thermal loading issue and increased our flight time under good conditions but made fawn confirmations more difficult due to low light conditions.

Forest canopy cover reduced ground visibility because TIR radiation was unable to penetrate through the forest canopy (Witczuk et al. 2018, Beaver et al. 2020). We also found that trees held residual heat from the previous day, which made locating fawn thermal signatures in forested areas more difficult (Steen et al. 2012, Beaver et al. 2020). The drone method may bias captures to grassland and scrub-shrub wetland habitats; however, most fawn capture techniques are inherently biased (Bishop et al. 2007, Chitwood et al. 2017) and our goal was to select areas that would maximize efficiency to locate fawns with the drone. Additionally, WMAs in southern Minnesota are primarily comprised of grasslands and wetlands. Thus, our captures were focused on the primary habitat type available to does and their fawns in our study area.

We found low fawn disturbance with all fawns remaining bedded and only a few lifting their head in response to the drone. Linchant et al. (2015) 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 to wildlife in general.

During our drone flights, we observed a multitude of other wildlife species, including: coyotes with pups, raccoons (*Procyon lotor*), muskrats (*Ondatra zibethicus*), mallards (*Anas platyrhynchos*), ring-necked pheasants (*Phasianus colchicus*), wild turkey (*Meleagris gallopavo*), and many small mammals and other bird species. 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). Drones show immense promise for the future of wildlife detection and estimation and, for ungulates, can provide a higher search efficiency compared to previous methods.

The 2021 collars did not entirely meet our expectations for collar fit and retention due to issues with premature expansion. But in 2022, we had fewer collars (2 versus 9) prematurely expanding (compared to 2021) and therefore a better fit on the fawns in 2022. We did not make any design changes to the expandable band folds or stitching between years, but we hypothesize the collar company's modification to the connection point (to include a two-point attachment to the package; Figures 5A and 5D) may have better dispersed the weight of the package and subsequently reduced pressure on the expandable loops. Unfortunately, one of the consequences of the modification was added pressure to the expandable band-GPS package, leading to increased issues with the expandable band breaking (Figures 5C and 5D). Fawns retained more collars throughout spring and summer in 2022 but we had continued issues with fawns retaining collars to 1-year of age (recruitment) and other important movement milestones (e.g., migration, dispersal; Beier 1995, Grovenburg et al. 2011a, Gilbertson et al. 2022). We also experienced an unavoidable issue of collars getting caught on fences (Figure 5B). Grovenburg et al (2014) reported similar issues in their South Dakota study area dominated by agriculture and livestock, with 93% of their prematurely shed collars being the result of fencing snags. Given the combination of heavily fragmented areas and adaptability of white-tailed deer to these environments, such retention issues could be an ongoing issue for studies using expandable collars (Grovenburg et al. 2014, Obermoller et al. 2018).

The use of expandable GPS collars on neonatal fawns has led to a much better understanding of fawn behavior and improved mortality response time and subsequently, improved accuracy to identify specific causes of mortality (Cristescu et al. 2022). Global Positioning System collars can also allow for the collection of activity data and fine-scale location data with vastly reduced monitoring efforts compared to VHF collars (Pellerin et al. 2008, Kochanny et al. 2009, Obermoller et al. 2018). Despite the benefits, researchers need realistic collar retention expectations and careful consideration of their research objectives when determining their sample size. We recommend researchers consider their specific ecological questions (e.g., summer survival, migration, winter habitat use) and account for potential retention issues (e.g., fences, thick cover) when determining their sample size. Collar retention considerations should include but are not limited to ungulate species, habitat type, and time frame of objectives. We also recommend continual communication with collar companies and fellow researchers regarding collar issues and potential modifications in future years. This iterative process is invaluable for future research to help meet the sample size requirements needed to properly address study objectives and gather time-sensitive ecological data for species management.

ACKNOWLEDGMENTS

We appreciate the assistance of S. Overfors, S. Stahlke, R. Kemna, K. Cotten, M. Rice, J. Menk, B. Smith, K. LaSharr, L. Messinger, and C. Scharenbroich for help locating fawn thermal signatures. We thank S. Fines and A. Sykes of Fines Aerial Imaging for flight preparations and conducting the drone flights at WMAs. We would also like to thank T. Klinkner for administrative assistance, K. Montgomery for drone contract assistance, and N. Davros for editorial reviews of research proposals and reports. This study was funded by MNDNR's Section of Wildlife and the Federal Aid in Wildlife Restoration (Pittman-Robertson) Program.

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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.

Capture method	Year	N	Effort	Study
Drone w/ thermal imaging (2021)	2021	75	3.1	Obermoller et al. (this study)
Drone w/ thermal imaging (2022)	2022	82	2.4	Obermoller et al. (this study)
Vaginal implant transmitter (VIT)	2003 - 2004	83	7 - 16	Bishop et al. 2007
Vaginal implant transmitter (VIT)	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

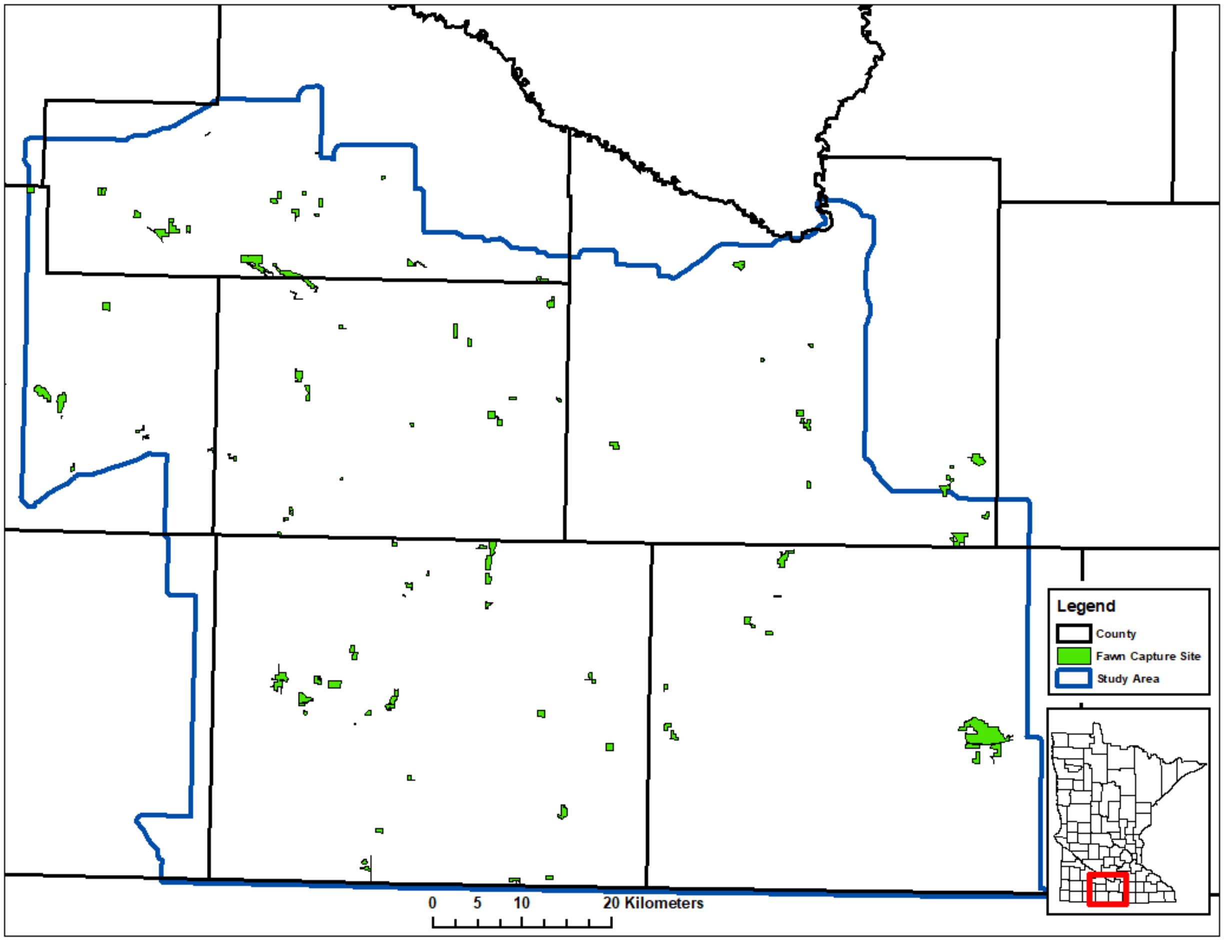

Figure 1. Study area including location of Wildlife Management Areas (green polygons) where white-tailed deer fawns were located and captured in south central Minnesota, USA during May-June 2021 and May 2022.

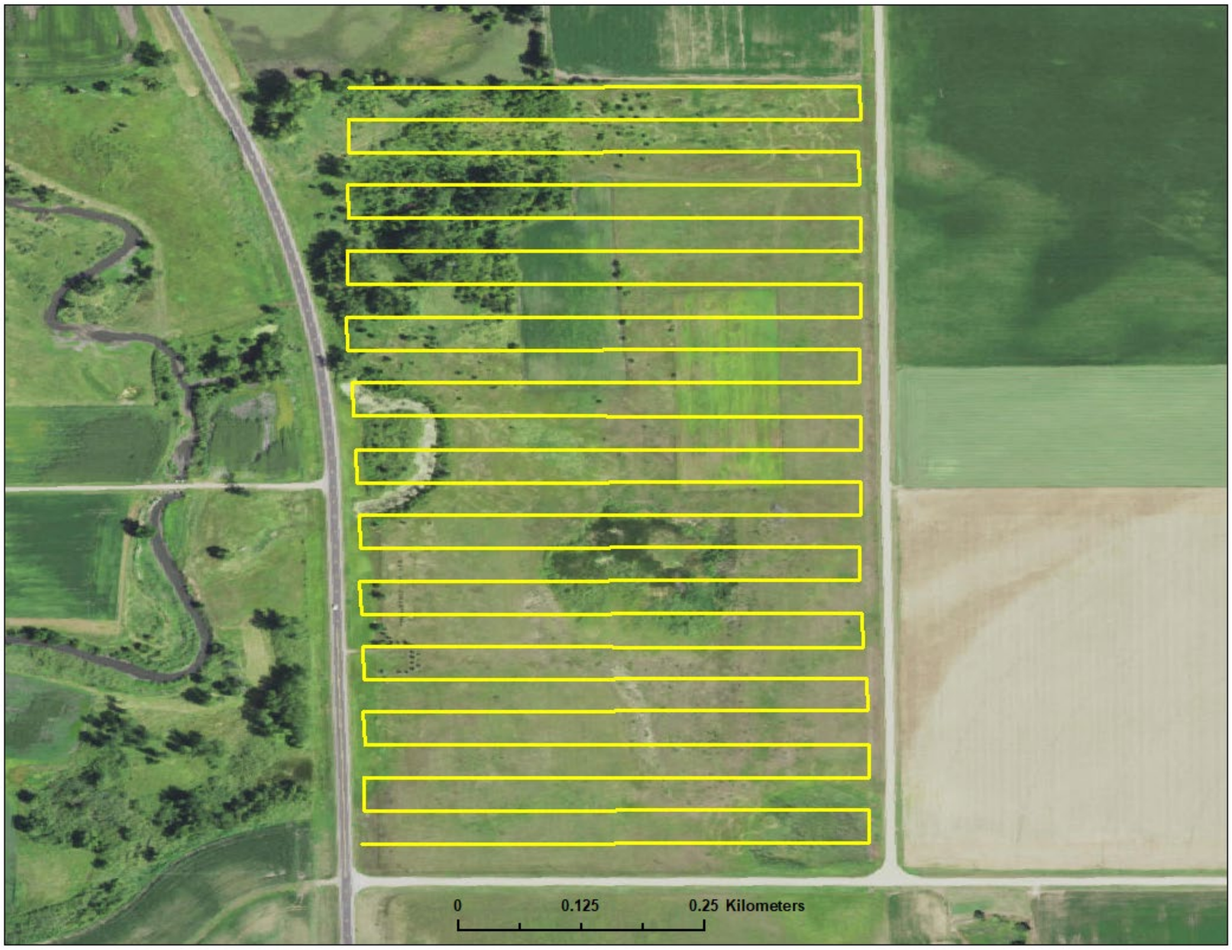

Figure 2. Flight path (yellow polylines) of the drone used to search for white-tailed deer fawns at Groebner Wildlife Management Area in south central Minnesota, USA, May-June 2021 and May 2022.

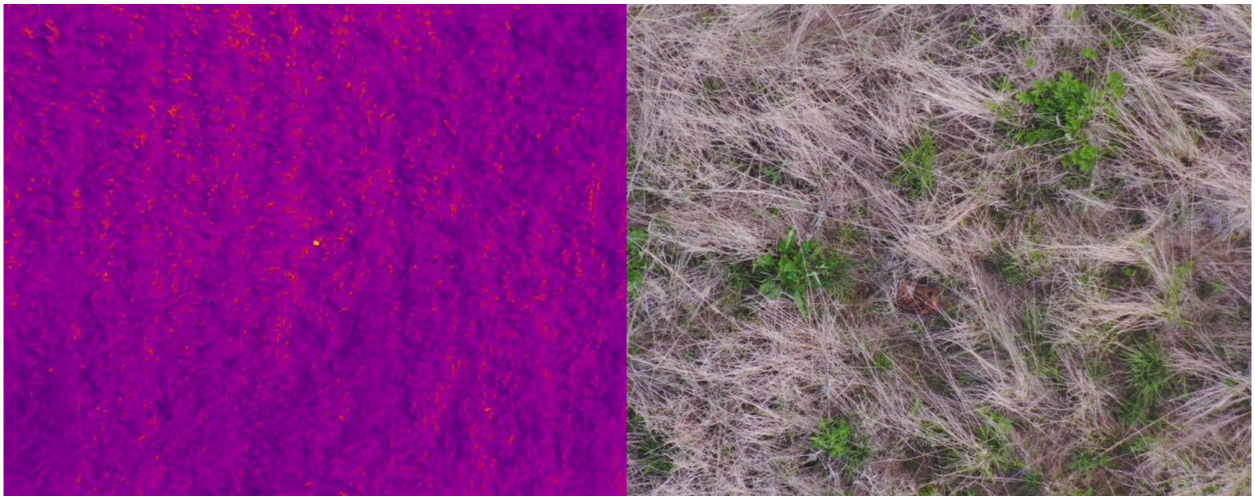

Figure 3. Thermal infrared image from a drone of a white-tailed deer fawn (left) and a zoomed-in image of the same fawn bedded in grass (right) in south central Minnesota, USA, May 2021.

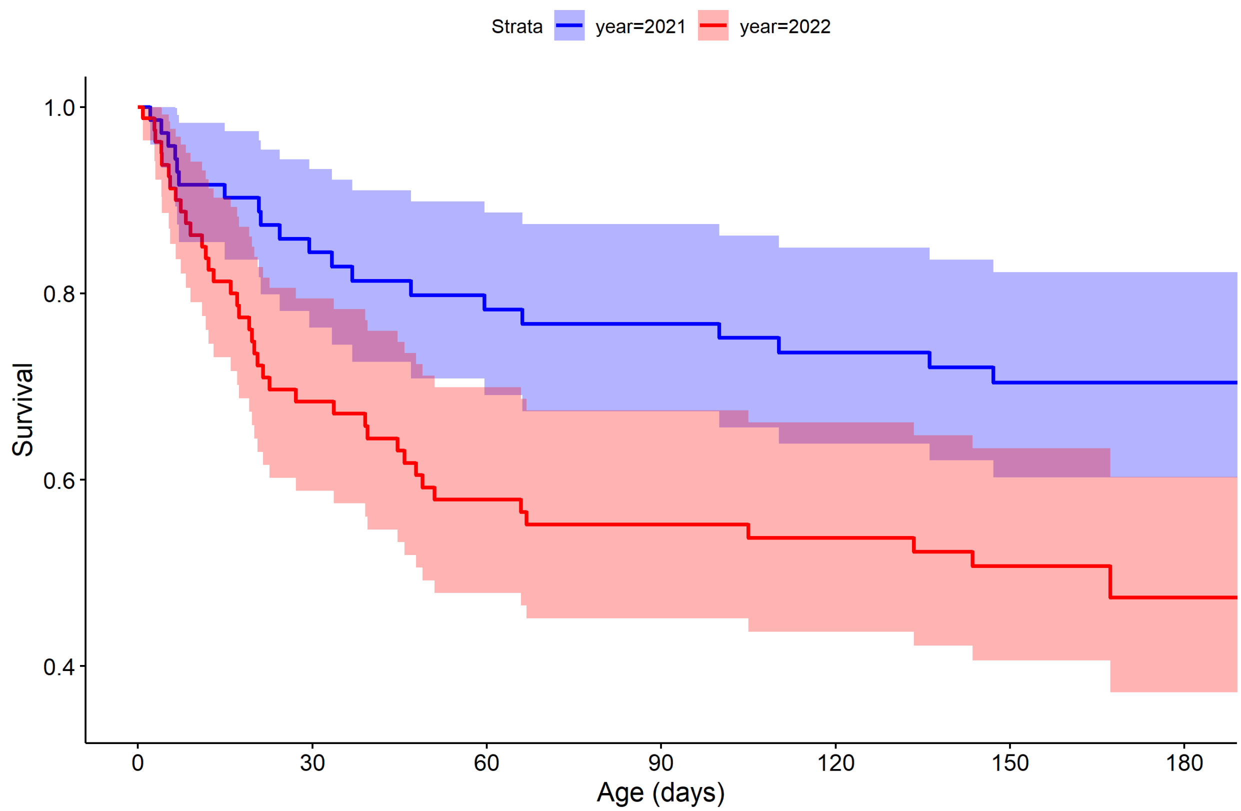

Figure 4. Cumulative daily survival (using Kaplan-Meier survival curve) of white-tailed deer fawns in south central Minnesota, USA, 2021 and 2022. Shaded areas represent 95% confidence intervals for the survival curves.

Figure 5. Vectronic Vertex MINI Globalstar expandable GPS collars deployed on white-tailed deer fawns in south central Minnesota, USA in 2021 and 2022. Panels depict: A) a collar that prematurely expanded, B) a collar caught on a fence, C) a collar initially caught on a fence that subsequently broke the expandable band, and D) a collar that got caught on vegetation and the expandable band broke.