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Improving Capture Methods for Neonate Ungulates

Matthew T. Turnley

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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ABSTRACT

Improving Capture Methods for Neonate Ungulates

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The capture of neonate ungulates has played an integral role in studies of habitat selection, phenology, survival, and other topics of ecological interest. However, neonates can be difficult for researchers to locate and capture. Neonate ungulates are born in habitats with reduced visibility, frequently spend time in a concealed, prone position, and may display cryptic coloration. In an attempt to improve researchers' likelihood of locating and capturing neonate ungulates, multiple capture methods have been developed. Much remains unknown about biases associated with capture methods and how to further improve capture methods once biases are understood. Our objectives were to determine if opportunistic captures of neonate mule deer (*Odocoileus hemionus*) bias estimates of litter size (Chapter 1) and to determine when searches for neonate elk (*Cervus canadensis*) should begin following parturition to maximize likelihood of capture while minimizing disturbance (Chapter 2). To complete our objectives, we analyzed data from 161 litters of mule deer and 55 attempted captures of neonate elk during 2019-2021 in Utah, USA. Estimates of litter size derived from opportunistic captures of mule deer were smaller than estimates derived from movement-based captures or captures completed with the aid of vaginal implant transmitters (VITs). The time elapsed between parturition and when searches were initiated for neonate mule deer did not influence estimates of litter size, but we could only analyze this relationship for VIT-aided captures within approximately 2 days of parturition. Until more data are available, we recommend that estimates of litter size for neonate mule deer be completed using movement-based or VIT-aided captures within approximately 2 days of parturition. When attempting to capture neonate elk, reducing the time elapsed between parturition and when searches were initiated resulted in a decreased search length, decreased distance traveled by the neonate, and increased likelihood of capture. We initiated searches as early as 3.6 hours post-parturition with no evidence of maternal abandonment and probability of capture was near or above 90% when searches were initiated within 10 hours of parturition. We recommend that searches for neonate elk be initiated 3.6-10 hours post-parturition. Future researchers can use utilize our results to perform captures of neonate ungulates that minimize bias, decrease disturbance, increase efficiency, and maximize the likelihood of capture success.

Keywords: capture methods, *Cervus canadensis*, elk, litter size, mule deer, neonates, *Odocoileus hemionus*, sampling bias, search initiation time, ungulates, Utah, vaginal implant transmitters

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CHAPTER I

Are Opportunistic Captures of Neonate Ungulates Biasing Estimates of Litter Size?

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ABSTRACT

The capture of neonate ungulates allows for collection of valuable ecological data, including estimates of litter size. However, varied methods used to capture neonate ungulates can result in sampling biases. Our objective was to determine if opportunistic captures of neonate ungulates bias estimates of litter size and investigate potential causes if a bias does exist. We analyzed data from 161 litters of mule deer (*Odocoileus hemionus*) sampled using 3 different capture methods during 2019-2021 in Utah, USA. Estimates of litter size derived from opportunistic captures were smaller than estimates derived from movement-based captures or captures completed with the aid of vaginal implant transmitters (VITs). The time elapsed between parturition and when searches for neonates were initiated did not influence estimates of litter size, but we could only analyze this relationship for VIT-aided captures. All of our VIT-aided captures occurred within approximately 2 days of parturition, while opportunistic captures of neonate mule deer typically occur between 3-7 days post-parturition. Until more data are available, we recommend that estimates of litter size for neonate mule deer be completed using movement-based or VIT-aided captures within approximately 2 days of the estimated time of parturition. Researchers should be aware of the biases of opportunistic captures and use caution when interpreting estimates of litter size derived from opportunistic captures.

INTRODUCTION

Multiple methods have been utilized to locate neonate ungulates and improve the likelihood of capture. Neonates can be captured opportunistically, without prior knowledge of a specific parturition event, by searching potential parturition sites (Ballard 1999, Pettorelli et al. 2005, Hiller et al. 2008). Opportunistic captures can also occur following the observation of postpartum behaviors by adult females (Grovenburg et al. 2010, Hurley et al. 2011, Pitman et al. 2014). In addition, opportunistic captures can be performed using aerial/terrestrial vehicles, audio recordings, spotlights, thermal sensors, or trained animals (Singer et al. 1997, Vreeland et al. 2004, Ditchkoff et al. 2005, Smith and Coblentz 2010, Hasapes and Comer 2017, Obermoller et al. 2021). Alternatively, neonate ungulates can be captured in a more targeted manner, aided by the knowledge of a specific parturition event. Parturient ungulates often display characteristic movement patterns, so targeted captures can occur by monitoring the movement of adult females with tracking collars (Kunkel and Mech 1994, DelGiudice et al. 2015, Severud et al. 2019). Targeted captures can also occur with the aid of vaginal implant transmitters (VITs), radio transmitters expelled at parturition that signal the occurrence of a parturition event (Bishop et al. 2007, Rearden et al. 2011, Dion et al. 2020).

The variety of methods developed to capture neonate ungulates has led to concerns of sampling biases. For example, age at capture tends to be higher for neonates captured using opportunistic methods than for neonates captured with the aid of VITs (Nelson et al. 2015, Kautz et al. 2019). Opportunistic captures are also more likely than VIT-aided captures to miss early-life mortalities, biasing estimates of survival and cause-specific mortality (Gilbert et al. 2014, Chitwood et al. 2017, Brackel et al. 2021). Moreover, opportunistic captures may not be randomly distributed, resulting in biased distributions of parturition events (Bishop et al. 2007, Bishop et al. 2011, Kilgo et al. 2012). An additional, untested bias when capturing neonate ungulates may be inaccurate estimates of litter size.

Litter size has major implications for individual fitness and population dynamics (for species with variable litter sizes). For example, litter size within a species tends to be positively related to the total body mass or relative body fat of female ungulates (Keech et al. 2000, Monteith et al. 2014, Frauendorf et al. 2016, Flajšman et al. 2018). Following parturition, female ungulates with larger litters incur greater lactation costs and have reduced fat reserves compared to conspecifics with smaller litters (Carl and Robbins 1988, Monteith et al. 2013, Simard et al. 2014). The implications of litter size also extend to neonate ungulates. Neonates in larger litters tend to have lower rates of survival than conspecifics in smaller litters (Johnstone-Yellin et al. 2009, Keech et al. 2011, Chitwood et al. 2015). Neonate mass within a species is also inversely related to litter size (Sæther and Heim 1993, Monteith et al. 2014, Michel et al. 2015). At the population level, rates of recruitment increase with larger litter sizes (Johnstone-Yellin et al. 2009). Despite the potential ecological implications of litter size, the potential biases associated with method of capture when assessing litter size of ungulates is unknown.

Our objective was to determine if opportunistic captures of neonate ungulates bias estimates of litter size and investigate potential causes if a bias does exist. We used captures of neonate mule deer (*Odocoileus hemionus*) and 3 capture methods (opportunistic, movement-based, and VIT-aided) as an initial case study. Because opportunistic methods tend to capture older individuals than alternative methods and bias estimates of survival, we hypothesized that opportunistic captures would also bias estimates of litter size (Gilbert et al. 2014, Nelson et al. 2015, Chitwood et al. 2017, Kautz et al. 2019, Brackel et al. 2021). We predicted that estimates of litter size derived from opportunistic captures would be smaller than estimates of litter size derived from movement-based captures or VIT-aided captures. Further, we predicted that capture method would influence duration of searches and distance between neonates from the same litter. In addition, because likelihood of capture often decreases as neonates age, we predicted that the time elapsed between parturition and when searches for neonates were initiated would be inversely related to estimates of litter size (Peterson et al. 2018, Turnley et al. In press).

MATERIALS AND METHODS

Study Area

We performed this study in the Book Cliffs (39.5°, -109.3°) and the Cache (41.7°, -111.5°) management units of Utah, USA (Fig. 1). Elevations in the Book Cliffs spanned from approximately 1,675 m to 2,590 m, average annual precipitation was 22.9 cm, and average annual temperature was 10.3° C (Western Regional Climate Center 2006). Terrain in the Book Cliffs consisted of cliff faces, ridges and valleys, and flatlands. Elevations in the Cache spanned from approximately 1,300 m to 2,800 m, average annual precipitation was 43.4 cm, and average annual temperature was 5.1° C (Western Regional Climate Center 2006). Terrain in the Cache consisted of ridges and valleys.

Predators of mule deer in the Book Cliffs and Cache included black bears (*Ursus americanus*), bobcats (*Lynx rufus*), coyotes (*Canis latrans*), and mountain lions (*Puma concolor*). Common vegetation in the Book Cliffs included bitterbrush (*Purshia tridentata*), Gambel oak (*Quercus gambelii*), mountain snowberry (*Symphoricarpos oreophilus*), quaking aspen (*Populus tremuloides*), sagebrush (*Artemisia* spp.), single-leaf pinyon (*Pinus monophylla*), Utah juniper (*Juniperus oteosperma*), and Utah serviceberry (*Amelanchier utahensis*). Common vegetation in the Cache included bluebunch wheatgrass (*Pseudoroegneria spicata*), Douglas fir

(*Pseudotsuga menziesii*), Engelmann spruce (*Picea engelmannii*), Idaho fescue (*Festuca idahoensis*), sagebrush, mountain mahogany *(Cercocarpus ledifolius*), and quaking aspen.

Adult Captures

An independent capture company (Helicopter Wildlife Services, Austin, TX, USA or Quicksilver Air Inc., Peyton, CO, USA) captured adult female mule deer via helicopter net-gunning during January-February of 2019-2021 (Barrett et al. 1982, Krausman et al. 1985). Following capture, the capture company hobbled and blindfolded animals to minimize stress and transported animals to a nearby processing site. At the processing site, we fitted animals with a tracking collar (G5-2DH, 595 g, Advanced Telemetry Systems, Isanti, MN, USA) which included global positioning system (GPS) technology and recorded coordinates every 2 hours. Collars were also equipped with a very high frequency (VHF) transmitter. In addition, we checked the pregnancy status of animals via transabdominal ultrasonography (Stephenson et al. 1995, Bishop et al. 2007). If an animal was pregnant, we inserted a VIT (M3930U, 23 g, Advanced Telemetry Systems) using a vaginoscope (Bishop et al. 2007, 2011). All VITs included light and temperature sensors to detect expulsion and a VHF transmitter. An ultra high frequency link between each collar and VIT allowed for notification of VIT expulsion, sent via email.

Neonate Captures

We captured neonate mule deer during May-July of 2019-2021 using 3 capture methods: opportunistic, movement-based, and VIT-aided. To perform opportunistic captures, we visually scanned potential mule deer habitat for adult females (White et al. 1972, Pojar and Bowden 2004). If females displayed typical postpartum behaviors (e.g., increased vigilance, reluctance to flee, social isolation, or vocalizations) or physical characteristics (e.g., enlarged udder or sunken flanks) we continued monitoring the female for evidence of neonates (White et al. 1972, Carstensen et al. 2003, Pojar and Bowden 2004). Upon observation of a neonate, we proceeded directly to the neonate's location. If we did not observe a neonate, we systematically searched the area surrounding the female's location.

To perform movement-based captures, we monitored movement patterns of adult females with tracking collars, but without a VIT (Peterson et al. 2018, Nicholson et al. 2019). If females displayed movement patterns indicative of parturition (e.g., a sudden, lengthy movement followed by a sustained reduction and localization of movement) we systematically searched the area surrounding the female's most recent coordinates (Vore and Schmidt 2001, Long et al. 2009, Peterson et al. 2018). The sample of collared females without a VIT included animals that previously expelled a VIT (and were incorporated into the study during a previous year) and animals that were not pregnant at the time of capture (but became pregnant during a subsequent year).

To perform VIT-aided captures, we systematically searched the area surrounding expelled VITs (Carstensen et al. 2003, Bishop et al. 2007, Quintana et al. 2016). Generally, we waited more than 3 hours after VIT expulsion before initiating a search to allow for female-neonate bonding to occur (Haskell et al. 2007, Tatman et al. 2011, Quintana et al. 2016). Wait times varied based on accessibility of parturition sites and the number of parturition events that occurred on the same day. If neonates were not located near the parturition site, we searched the female's most recent coordinates.

Data Collection

Following capture of a neonate, we blindfolded the animal, completed processing with nitrile gloves, recorded GPS coordinates of the capture location, and fitted each neonate with an expandable tracking collar (M4230BU, 125g, Advanced Telemetry Systems). If a lone neonate was found, we began searching the surrounding area for additional neonates from the same litter. We estimated litter size based on the number of neonates located during our search, even if neonates fled before capture could occur. If it became too dark to locate neonates, we postponed searches until the next day. We recorded search duration as the time spent searching for neonates from the same litter after arriving at an animal's recent locations or the VIT location. All methods were approved by the Institutional Animal Care and Use Committee at Brigham Young University (protocol 19-0202) and followed guidelines from the American Society of Mammalogists (Sikes et al. 2016).

Data Analysis

To determine if opportunistic captures biased estimates of litter size, and why any bias may have occurred, we analyzed capture data and estimates of litter size using 2 logistic regression models and 3 linear regression models. We used a mixed-effects logistic regression to examine the relationship between capture method and litter size (coded as litter size of 1 = 0, litter size of 2 = 1). We did not censor any estimates of litter size from the logistic regression. We used a mixed-effects linear regression to examine the relationship between capture method and search duration, censoring searches when ≥ 1 neonate was found deceased ($n = 11$) or when search duration was not recorded ($n = 6$). We also used a mixed-effects linear regression to examine the relationship between capture method and distance between neonates from the same litter, censoring litters when ≥ 1 neonate was found deceased ($n = 6$), ≥ 1 neonate fled before capture could occur (*n* = 3), neonates were captured on different dates (*n* = 2), or when coordinates were not recorded (*n* = 1).

The time elapsed between parturition and initiating a search, search initiation time, could only be calculated for VIT-aided captures (using VIT expulsion as the estimated time of parturition). Thus, we analyzed the influence of search initiation time using VIT-aided captures only. We used a mixed-effects logistic regression to examine the relationship between search initiation time and litter size, censoring litters when search initiation was not recorded (*n* = 5). We used an additional mixed-effects linear regression to examine the relationship between search initiation time and distance between neonates from the same litter, censoring litters when ≥ 1 neonate was found deceased (*n* = 5) and when coordinates were not recorded (*n* = 1).

In all models, we included management unit and year as random effects and confirmed that relevant assumptions were met. For our logistic regression models, we confirmed that samples were independent, continuous explanatory variables had linearity in the logit, explanatory variables were not correlated, response variables were binary, and outliers were not strongly influential (Stoltzfus 2011). For our linear regression models, we confirmed that samples were independent, explanatory and response variables were linearly related, explanatory variables were not correlated with error terms, response variables were continuous, errors had constant variance, and errors were normally distributed (Casson and Farmer 2014). We used an α-value of 0.05 in all interpretations. We analyzed data using Program R version 4.0.2 and the lme4 package (Bates et al. 2015, R Core Team 2020).

RESULTS

We analyzed data from 161 litters (238 neonates) of mule deer captured over a period of 3 years. We located 64 litters using opportunistic methods, 14 litters using movement-based methods, and 83 litters using VIT-aided methods. Of the litters we analyzed, 84 (52.2%) were comprised of 1 neonate and 77 (47.8%) were comprised of 2 neonates. We did not find evidence of any litters being comprised of more than 2 neonates.

Estimates of litter size derived from opportunistic captures were smaller than estimates of litter size derived from movement-based (β = 1.3, OR = 3.7, 95% CI = 1.1–12.7, SE = 0.6, z_{11} = 2.1, P = 0.03) or VIT-aided captures (β = 1.5, OR = 4.6, 95% CI = 2.2–9.6, SE = 0.4, z_{80} = 4.2, $P \leq 0.001$). Estimates of mean (± SE) litter size derived from opportunistic captures, movement-based captures, and VIT-aided captures were 1.3 ± 0.1 neonates, 1.6 ± 0.1 neonates, and 1.6 ± 0.1 neonates, respectively (Fig. 2). Search durations associated with opportunistic captures were shorter than search durations associated with movement-based (β = 39.2, SE = 6.8, t_{10} = 5.8, $P \leq 0.001$, R^2m = 0.2, R^2c = 0.2) or VIT-aided captures (β = 9.3, SE = 4.2, t_{73} = 2.2, P = 0.03, R^2m = 0.2, R^2c = 0.2). Mean (± SE) search duration associated with opportunistic captures, movement-based captures, and VIT-aided captures was 13.1 ± 1.9 minutes, 50.5 ± 11.0 minutes, and 20.1 ± 2.7 minutes, respectively (Fig. 3). Distances between neonates from the same litter associated with opportunistic captures were shorter than distances associated with movement-based captures (β = 1.4, SE = 0.6, t_5 = 2.4, P = 0.02, R^2m = 0.1, R^2c = 0.2), but were not different than distances associated with VIT-aided captures (β = 0.9, SE = 0.5, t_{43} = 1.9, P = 0.06, R^2m = 0.1, R^2c = 0.2). Mean (± SE) distance between neonates from the same litter associated with opportunistic captures, movement-based captures, and VIT-aided captures was 1.7 ± 1.1 m, 21.9 ± 12.2 m, and 5.7 ± 1.2 m, respectively (Fig. 4).

Based on observations from VIT-aided captures only, there was no relationship between search initiation time and litter size (β = –0.01, SE = 0.02, z_{75} = –0.6, P = 0.57). Moreover, there was no relationship between search initiation time and distance between neonates from the same litter (β = 0.03, SE = 0.02, t_{43} = 1.6, P = 0.12). Search initiation time ranged from 2.6 hours to 49.6 hours and mean (± SE) search initiation time was 14.9 ± 1.3 hours.

DISCUSSION

Our results indicate that estimates of litter size derived from opportunistic captures were smaller than estimates of litter size derived from movement-based captures or VIT-aided captures. All capture methods likely had some level of detection failure when estimating litter size, but opportunistic captures appear to increase the likelihood of detection failure. Sampling biases associated with opportunistic captures are well recorded, especially when compared to VIT-aided captures (Gilbert et al. 2014, Nelson et al. 2015, Chitwood et al. 2017, Kautz et al. 2019, Brackel et al. 2021). Much less is known about potential sampling biases of movement-based captures. While our study provides one example of movement-based methods minimizing bias when capturing neonate ungulates, our sample size for litters associated with movement-based captures was relatively small (n = 14). Our sample size for litters associated with movement-based captures that were comprised of 2 neonates was even smaller (n = 8). We present interpretations of our results associated with movement-based captures not as concrete conclusions, but as potential patterns to inspire future research (Bissonette 1999). Movement-based captures may be utilized more often as fine-scale movement data increases in availability and statistical analyses to detect parturition improve (Peterson et al. 2018, Nicholson et al. 2019, T. A. Hughes, unpublished data).

Our investigation into why estimates of litter size were smaller for opportunistic captures revealed that search durations associated with opportunistic captures were shorter than search durations associated with movement-based and VIT-aided captures. This difference in search durations was likely due to variations in search procedures between capture methods. Searches associated with opportunistic captures typically began when we arrived at the location where a neonate was observed. Searches for movement-based captures always began prior to the observation of a neonate, and searches for VIT-aided captures began prior to the observation of a neonate if there was not a neonate located where the VIT was expelled. In other words, there was considerable variation among methods in the amount of time elapsed to find the first neonate, with opportunistic captures having the least elapsed time and movement-based captures having the most elapsed time. It would have been more appropriate to analyze search duration for each capture method after the first neonate was located, but these data were not available. While we acknowledge that variance in search duration may have influenced estimates of litter size, estimates derived from VIT-aided captures and movement-based captures did not differ despite VIT-aided captures having shorter search durations than movement-based captures. Thus, we do not believe search duration was entirely responsible for the observed difference in litter sizes.

We also determined that the distance between neonates from the same litter was shorter for litters associated with opportunistic captures than for litters associated with movement-based captures. The distance between neonates from the same litter associated with opportunistic captures did not differ from litters associated with VIT-aided captures. While timing is unclear, female ungulates often separate neonates soon after parturition (White et al. 1972, Barrett 1984, Riley and Dood 1984, Blank et al. 2015). Distance of separation varies, but can be more than 400 m for mule deer (Riley and Dood 1984). Our seemingly counterintuitive finding of distances between neonates from the same litter not differing between opportunistic captures and VIT-aided captures may therefore be a result of detection bias. When using opportunistic captures, we may have failed to detect multiple neonates from the same litter unless neonates were close together. While we attempted to exercise equal effort in all searches, sampling protocols that dictated a standardized search distance (and search duration) may have helped to minimize sampling bias (Carstensen et al. 2003, Pojar and Bowden 2004).

Our analysis of the influence of search initiation time provided additional insights on postpartum behavior and the separation of neonates. We determined that search initiation time did not influence estimates of litter size or the distance between neonates from the same litter. However, our analysis of search initiation time only included VIT-aided captures, which all occurred within approximately 2 days of parturition and 50.0% occurred within 10 hours of parturition. Mean age at capture for neonate mule deer captured using opportunistic methods generally ranges between 3-7 days (Steigers and Flinders 1980, Pojar and Bowden 2004, Gilbert et al. 2014). We suspect the increased search initiation times associated with opportunistic captures influenced estimates of litter size, but could not confirm this with our data. The likelihood of capturing neonate mule deer decreases when searches are initiated ≥ 4 days post-parturition (Peterson et al. 2018). In addition, the age difference between neonates captured using VITs and neonates captured opportunistically is large to enough to result in differential estimates of survival (Gilbert et al. 2014, Chitwood et al. 2017, Brackel et al. 2021). An increased number of mortality events may also have contributed to the smaller estimates of litter size associated with opportunistic captures. More work should be done to fully elucidate the influences of search initiation time and the reasons why opportunistic captures result in sampling bias.

Management Implications

Capturing neonate mule deer using opportunistic methods results in smaller estimates of litter size compared to movement-based and VIT-aided captures. While the time elapsed between parturition and initiating a search for neonates may influence estimates of litter size, there is no influence within 49.6 hours of parturition. Until more data are available, completing captures of neonate mule deer using movement-based or VIT-aided captures within approximately 2 days of parturition will ensure minimal bias in estimations of litter size. Managers should be aware of the biases of using different methods to capture neonate ungulates and use caution when making ecological interpretations, especially when using opportunistic methods.

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FIGURES

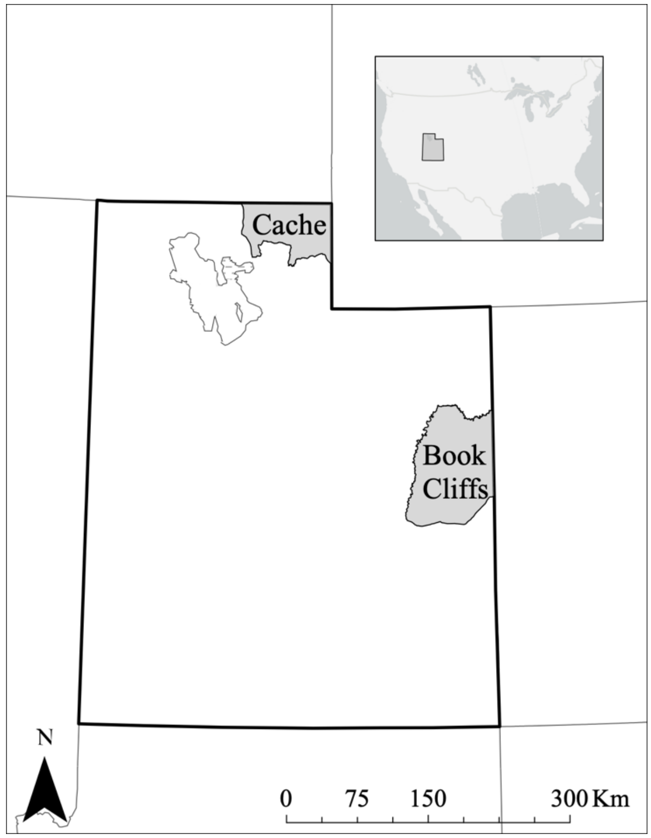

Figure 1. Study areas (shaded and labeled) associated with captures of neonate mule deer during 2019-2021 in Utah, USA. A total of 128 neonates were captured in the Book Cliffs management unit and 110 neonates were captured in the Cache management unit.

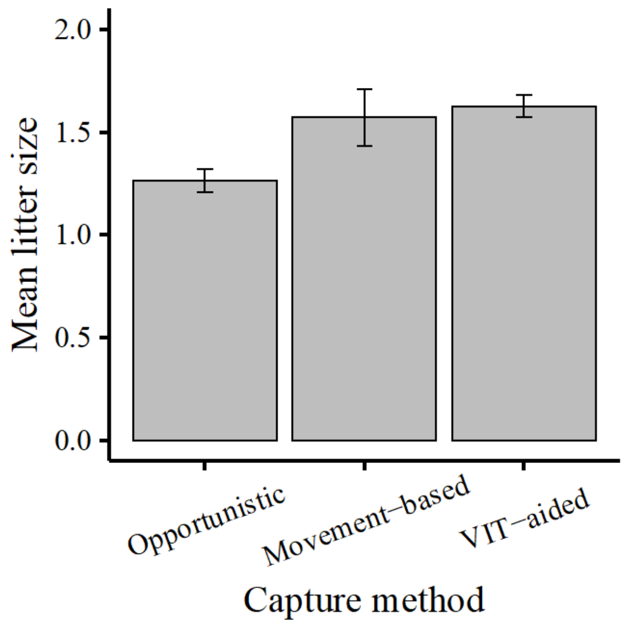

Figure 2. Estimates of mean litter size derived from captures of neonate mule deer during 2019-2021 in Utah, USA. Capture methods included visually scanning for females displaying postpartum behaviors (opportunistic), monitoring movement patterns of females with tracking collars (movement-based), and searching the area surrounding expelled vaginal implant transmitters (VITs; VIT-aided). Error bars represent standard error.

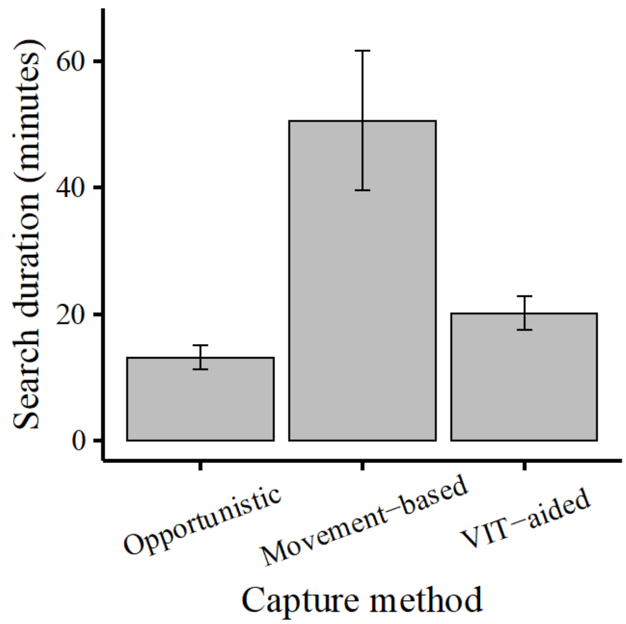

Figure 3. Mean search durations associated with captures of neonate mule deer during 2019-2021 in Utah, USA. Capture methods included visually scanning for females displaying postpartum behaviors (opportunistic), monitoring movement patterns of females with tracking collars (movement-based), and searching the area surrounding expelled vaginal implant transmitters (VITs; VIT-aided). Error bars represent standard error.

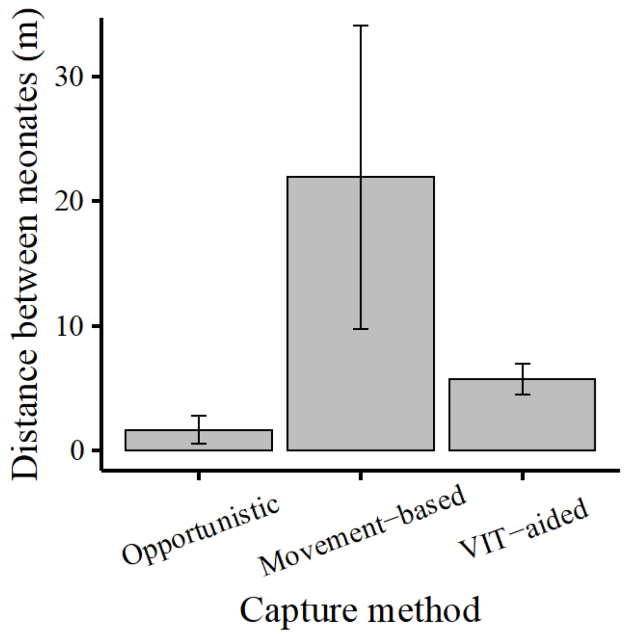

Figure 4. Mean distances between neonates from the same litter associated with captures of neonate mule deer during 2019-2021 in Utah, USA. Capture methods included visually scanning for females displaying postpartum behaviors (opportunistic), monitoring movement patterns of females with tracking collars (movement-based), and searching the area surrounding expelled vaginal implant transmitters (VITs; VIT-aided). Error bars represent standard error.

CHAPTER II

Optimizing Methods for Capturing Neonate Elk When Using Vaginal Implant Transmitters

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ABSTRACT

The ability to capture and monitor neonate ungulates has been enhanced by vaginal implant transmitters (VITs). Improving capture methodology when using VITs will further increase the likelihood of capturing neonates. We analyzed data from 55 attempted captures of neonate elk (*Cervus canadensis*) in Utah, USA during 2019-2020 to determine when searches for neonate elk should begin to maximize likelihood of capture while minimizing disturbance. Reducing the time elapsed between parturition and search initiation resulted in a decreased search length, decreased distance traveled by the neonate, and increased likelihood of capture. We initiated searches as early as 3.6 hours post-parturition with no evidence of maternal abandonment. Probability of capture was near or above 90% when searches were initiated within 10 hours of parturition. We recommend that researchers initiate searches 3.6-10 hours post-parturition to allow for capture attempts that are effective, efficient, and minimally disruptive.

INTRODUCTION

Vaginal implant transmitters (VITs), radio transmitters designed to be expelled at parturition, were developed to aid the capture and monitoring of neonate ungulates (Garrott and Bartmann 1984). Generally, VITs designed for ungulates are T-shaped, with flexible wings to hold the transmitter in the vagina until parturition (Johnson et al. 2006). Very high frequency (VHF) transmissions produced by the VIT allow researchers to locate expelled VITs and parturition sites. At least 9 species of ungulates in North America have been studied using VITs: bighorn sheep (*Ovis canadensis*), bison (*Bison bison*), elk (*Cervus canadensis*), feral pigs (*Sus scrofa*), moose (*Alces alces*), mule deer (*Odocoileus hemionus*), muskoxen (*Ovibos moschatus*), pronghorn (*Antilocapra americana*), and white-tailed deer (*Odocoileus virginianus*) (Kaze et al. 2016, Conant et al. 2020, Schmidt et al. 2020).

Advances in technology have resulted in decreased time between VIT expulsion and researchers' awareness of expulsion (Dion et al. 2019). Early VITs were located using repeated monitoring of VHF transmissions activated by a motion sensor in the VIT (Bowman and Jacobson 1998). Because the motion sensor could still be affected by animal movements at the parturition site, VITs were developed using VHF transmissions activated by the change in temperature when a VIT is expelled (Barbknecht et al. 2009). Modern VITs are now capable of linking with global positioning system (GPS) collars worn by the mother via ultra high frequency (UHF) transmissions. The GPS collars can send notification, via satellite, when a change in temperature or light is detected by the VIT. Notification of VIT expulsion eliminates the need for repeated monitoring in the field and allows for more accurate estimation of timing of parturition.

Capturing neonate ungulates with the aid of VITs has advantages over alternative captures methods, which often are challenging and time-intensive (Carstensen et al. 2003, Swanson et al. 2008, Conant et al. 2020). Neonates are typically captured without VITs through the observation of potential post-parturition behaviors by adult females (Vore and Schmidt 2001, Vreeland et al. 2004, Seward et al. 2005, Hurley et al. 2011, Pitman et al. 2014). However, neonates frequently remain in a stationary, concealed position and adult females tend to select parturition sites with high vegetative cover, increasing the difficulty of locating neonates through opportunistic observation (Fisher et al. 2002, Barbknecht et al. 2011, Shuman et al. 2018). Using VITs can reduce capture bias as a result of observer skill, visibility levels, and individual animal behavior. Moreover, VITs allow for accurate mother-neonate pair identification, increase the accuracy of early-life history assessments such as cause-specific mortality, and may reduce disturbances associated with search length when compared to observational capture methods (Carstensen et al. 2003, Bishop et al. 2007, Chitwood et al. 2017).

Improving capture methodology when using VITs would further benefit managers and researchers by increasing the effectiveness and efficiency of capture attempts. As modern VITs provide near-instant notification of parturition, guidance on when to initiate ground searches for neonate ungulates is of particular interest. Recommendations regarding when to initiate searches for neonate elk following parturition are non-existent or lack supporting data (Livezey 1990). There are multiple factors to consider when attempting to optimize the timing of neonate searches. Arriving too early may interrupt a prolonged labor, mother-neonate bonding, or other post-parturition events while arriving too late may lead to a decrease in the likelihood of capture, inaccurate early-life history assessments, or increase disturbance time due to search length. All factors should be balanced by managers and researchers as the interruption of mother-neonate bonding and lengthy, stressful disturbances may increase the likelihood of maternal abandonment in ungulates (Livezey 1990, Delgiudice et al. 2018). Although exact timing is unclear, female elk move neonates from the parturition site soon after parturition, so the optimal time to initiate searches for neonates may be immediately following mother-neonate bonding (Harper et al. 1967, Johnson et al. 2006). Bonding in ungulates appears to occur rapidly, but there is no clear consensus regarding how long researchers should avoid disturbing newborns and wait times have ranged from 3 hours to 2 days (Lent 1974, Livezey 1990, Pitman et al. 2014).

Our objective was to determine when ground searches for neonate elk should begin following parturition to maximize likelihood of capture while minimizing disturbance to adult females and their offspring. We hypothesized that optimal search time would occur immediately after bonding and that bonding would occur within 4 hours of parturition. We believed this time frame, which fell within the range of wait times used by previous researchers, would allow for cleaning and nursing to occur (Livezey 1990). More specifically, we hypothesized that initiating searches as soon as possible after bonding would lead to a maximal likelihood of capture, minimal search length, minimal distance traveled from the parturition site by neonates, and minimal maternal abandonment.

MATERIALS AND METHODS

Study Area

We conducted our study during 2019-2020 in the Book Cliffs region (39.5°, -109.3°) of east-central Utah. Elevations ranged from approximately 1,675 m to 2,590 m. On the northern edge of the study area, average annual precipitation was 22.5 cm and average annual temperature was 9.0° C (Western Regional Climate Center 2006). On the southern edge of the study area, average annual precipitation was 23.3 cm and average annual temperature was 11.5° C (Western

Regional Climate Center 2006). Topography in the region was diverse, containing sheer cliff faces, extensive ridges and valleys, and flatlands at lower elevations.

Elk co-occurred with native and non-native ungulates, including bighorn sheep, bison, cattle (*Bos taurus*), feral horses (*Equus caballus*), mule deer, and pronghorn. Predators of elk in the Book Cliffs included black bears (*Ursus americanus*), bobcats (*Lynx rufus*), coyotes (*Canis latrans*), and mountain lions (*Puma concolor*). Common vegetation consisted of bitterbrush (*Purshia tridentata*), Gambel oak (*Quercus gambelii*), mountain snowberry (*Symphoricarpos oreophilus*), quaking aspen (*Populus tremuloides*), sagebrush (*Artemisia* spp.), single-leaf pinyon (*Pinus monophylla*), Utah juniper (*Juniperus oteosperma*), and Utah serviceberry (*Amelanchier utahensis*).

Adult Captures and VIT Insertion

During February 2019 and 2020, the Utah Division of Wildlife Resources (UDWR) captured adult female elk across the study area using helicopter net-gunning or darting (Barrett et al. 1982, Krausman et al. 1985, McCorquodale et al. 1988). For dart captures, they used thiafentanil (10 mg/ml, Wildlife Pharmaceuticals, Laramie, WY, USA) and xylazine (300 mg/ml, Wildlife Pharmaceuticals) delivered in a barbed dart (type U, 1.5 ml, Pneudart, Williamsport, PA, USA) to chemically immobilize elk and administered naltrexone (50 mg/ml, Wildlife Pharmaceuticals) intramuscularly to reverse the effects. After capture, animals were restrained and blindfolded to minimize stress. Each animal was fitted with a tracking collar (G5-2DH, 657 g, Advanced Telemetry Systems, Isanti, MN, USA) equipped with GPS technology and a VHF transmitter. Collars were programmed to record coordinates every 2 hours.

In addition, the UDWR assessed pregnancy of collared elk using transabdominal ultrasonography (Stephenson et al. 1995, Bishop et al. 2007). If the ultrasound (IBEX PRO, E.I.

Medical Imaging, Loveland, CO, USA) revealed an individual was pregnant, the UDWR placed a VIT (M3960U, 41 g, Advanced Telemetry Systems) with the aid of a vaginoscope (Bishop et al. 2007, 2011). The VITs were equipped with light and temperature sensors to detect expulsion (as determined by a major increase in light exposure or a drop in temperature below 32° C) and a VHF transmitter to aid in locating the expelled VIT. Collars and VITs also had Neolink (Advanced Telemetry Systems) capability, which included a UHF link between the collar and VIT, allowing for near-instant notification of parturition sent via email. All procedures were approved by the Institutional Animal Care and Use Committee at Brigham Young University (protocol 19-0202) and consistent with guidelines from the American Society of Mammalogists (Sikes et al. 2016).

Neonate Captures

During May-July 2019 and 2020, we captured neonate elk with the aid of VITs. To allow for cleaning of the offspring and mother-neonate bonding, we attempted to wait 4 hours after notification of VIT expulsion before initiating ground searches (a wait time between 3-4 hours occurred on 2 occasions). While the majority of wait times in 2019 were longer than 7 hours, wait times were generally closer to 4 hours in 2020 due to a change in capture protocol. Wait times were increased when parturition occurred at night or multiple parturition events occurred on the same day. We used GPS coordinates and VHF transmissions to locate adult females. If neonates were not immediately found at the female's location, we examined the VIT location – the expected parturition site. If neonates were not immediately found at either location, we began searching the surrounding areas and commenced recording search length. We limited searches to 3 hours to minimize disturbance, categorizing searches as unsuccessful if no neonate was located.

If a neonate was located, further precautions were taken to minimize disturbance and capture-related stress. We handled neonates with nitrile gloves, blindfolded neonates during handling, kept noise to a minimum, and returned individuals to the location where they were first observed before release. We fitted neonates with expandable VHF collars (M4230BU, 125g, Advanced Telemetry Systems) and recorded GPS coordinates of the capture location. Neonate collars also had Neolink technology, allowing for adult collars to send notification of mortality if there was no movement of the neonate collar for 4 hours. We monitored survival of neonates for 1 year post-parturition. Any mortalities were investigated for signs of maternal abandonment, such as a lack of milk in the stomach, close proximity to the release location, or a lack of mortal injuries or defects (Livezey 1990). We simultaneously monitored survival of adult females (collars were programmed with an 8-hour mortality sensor) to ensure that females were alive when investigating the potential for maternal abandonment.

Data Analysis

To determine how soon after parturition searches for neonate elk should begin, we analyzed capture results using a logistic regression and 2 linear regression models. We established the time elapsed between VIT expulsion and initiating a search (search initiation time) for every capture attempt. We calculated distance traveled from parturition sites by captured neonates using coordinates collected at the parturition site (VIT location) and the location of the neonate at capture. We calculated age at capture using VIT expulsion as the estimated time of parturition. Also, we calculated the proportion of attempted captures that were successful based on all attempts in which VITs remained functional and appeared to be expelled at a parturition site. We used a logistic regression to examine the relationship between search initiation time and the probability of capture (coded as successful capture attempt = 1, unsuccessful capture attempt = 0). Due to incomplete capture data (i.e., search initiation time not recorded), we left-censored 3 of the 55 capture attempts from our logistic regression analysis. We included only fixed parameters in the analysis and limited models to a single variable given the small sample size of unsuccessful searches (*n* = 7) (Peduzzi et al. 1996). Subsequently, we used a mixed-effects linear regression model to examine the relationship between search initiation time and search length for all captures. To elucidate when neonates moved from the parturition site, we used a mixed-effects linear regression model to examine the relationship between neonate age and distance traveled from the parturition site by captured neonates. Due to incomplete capture data, we left-censored 2 of the 48 captures from both linear models. We included year as a random intercept in both linear models. We confirmed that appropriate assumptions were met for each model and used an α-value of 0.05 in all interpretations (Stoltzfus 2011, Casson and Farmer 2014). To monitor potential impacts of disturbance, we calculated the number of neonates that appeared to be abandoned. We did not censor any individuals from the abandonment calculation. We analyzed all data using Program R version 4.0.2 and the lme4 package (Bates et al. 2015, R Core Team 2020).

RESULTS

We analyzed data from 55 attempted captures of neonate elk over a period of 2 years in east-central Utah. Search initiation time for all capture attempts ranged from 3.6 hours to 30.9 hours and mean search initiation time was 8.6 hours (SE = 0.8). All capture attempts with a search initiation time < 6.3 hours resulted in the successful capture of a neonate. Search length for successful captures ranged from 0 minutes to 130 minutes and mean search length for successful captures was 16.1 minutes (SE = 4.3). Distance traveled from the parturition site by captured neonates ranged from 0.0 km to 1.2 km and mean distance traveled by captured neonates was 0.1 km (SE = 0.03). We captured 16 neonates that had not yet moved from the parturition site, all of which were < 7.7 hours old. We also captured 15 neonates < 7.7 hours old that had moved, but all were located < 0.1 km from the parturition site. The mean age of a neonate that had not yet moved from the parturition site was 5.8 hours old (SE = 0.2), while the mean age of a neonate that had moved was 10.0 hours old (SE = 1.2).

In 2019, we captured a neonate on 63.2% of capture attempts (n = 19). There were 2 VITs expelled prior to parturition in 2019 which were not included in the analysis. In 2020, we captured a neonate on 100% of capture attempts (n = 36). No VITs were expelled prior to parturition in 2020. We captured a neonate on 87.3% of capture attempts throughout the study period (n = 55).

There was a negative relationship between search initiation time and probability of capture ($\beta = -0.13$, SE = 0.06, $z_{50} = -2.1$, $P = 0.04$). The odds ratio for the β estimate was 0.88 (95% CI = 0.77–0.99). Probability of capture was near or above 90% when search initiation times were between 0–10 hours, but declined to < 70% when search initiation times reached 20 hours (Fig. 5). We detected a positive relationship between search initiation time and search length for successful capture attempts ($\beta = 0.06$, SE = 0.01, $t_{44} = 4.35$, $P \leq 0.001$, $R^2 = 0.30$; Fig. 6A). Also, there was a positive relationship between neonate age and distance traveled from the parturition site by captured neonates ($\beta = 0.04$, SE = 0.01, $t_{44} = 6.91$, $P \leq 0.001$, $R^2 = 0.51$; Fig. 6B). We did not detect any maternal abandonment during the study period. Causes of neonate mortality included predation, birth complication, vehicle collision, and accident-induced injury.

DISCUSSION

Our results indicate that search initiation time influenced the likelihood of capturing neonate elk. While successful capture attempts had varying search initiation times, all capture attempts with a search initiation time < 6.3 hours were successful. Initiating searches before 6.3 hours may maximize the likelihood of successful captures. Our proportion of successful capture attempts in 2020 was 36.8% greater than in 2019, aligning with an average search initiation time in 2020 that was 2.8 hours less than in 2019. While some of the increased success could be attributed to increased experience by the field crew, both years had novel researchers and the only change in search methodology across the 2-year study was to decrease the time elapsed between VIT expulsion and when we initiated a search. Consequently, we believe search initiation time is the factor most responsible for the increased success observed in 2020. Our proportion of successful capture attempts for the entire study (87.3%) was higher than the proportion reported from a previous study (64.3%) using a similar calculation methodology (i.e., based on all capture attempts in which VITs remained functional and appeared to be expelled at a parturition site; Johnson et al. 2006).

We determined that search initiation time influenced the length of searches for neonate elk. While there is variability in the length of time between parturition and when neonates move from the parturition site, none of the neonates we captured at the parturition site were > 7.7 hours old. Locating neonates before 7.7 hours post-parturition may increase the likelihood of a neonate still being present at the parturition site, minimizing search length. An accurate assessment of the mother's location also may decrease search length, as mothers were frequently located near neonates.

Maternal abandonment has occurred after capturing neonate elk, but search initiation times were not reported (Johnson et al. 2019, Simpson et al. 2020). On 2 occasions we had search initiation times occur earlier than 4 hours (at 3.6 hours and 3.8 hours) with no evidence of maternal abandonment. It is possible that searches for neonate elk may be initiated even earlier than 3.6 hours post-parturition without resulting in maternal abandonment (while further increasing likelihood of capture and decreasing search length), but we could not evaluate earlier search initiation times based on data. In addition, reducing the time elapsed between VIT expulsion and initiating a search may decrease the chances that neonates will be predated prior to capture. While predation of neonate elk prior to capture has been reported, we captured all neonates prior to mortality in 2020 with a mean search initiation time of 7.7 hours (SE = 0.9) (Lehman et al. 2018). We were unable to confirm that zero mortalities occurred prior to capture in 2019 due to unsuccessful capture attempts. Future monitoring of search initiation time and cause-specific mortality will help determine how early searches for neonate elk can occur with minimal disturbance.

Management Implications

As VITs continue to be utilized in the capture of neonate ungulates, capture methodology can be improved by adjusting search initiation time. Reducing search initiation time increases search effectiveness and efficiency. Waiting 10 hours post-parturition may be an estimated upper limit for a search initiation time that still leads to a near-maximal likelihood of capture for neonate elk. Until maternal abandonment is better understood in elk, waiting 3.6 hours post-parturition may be an estimated lower limit for a search initiation time that does not result in abandonment.

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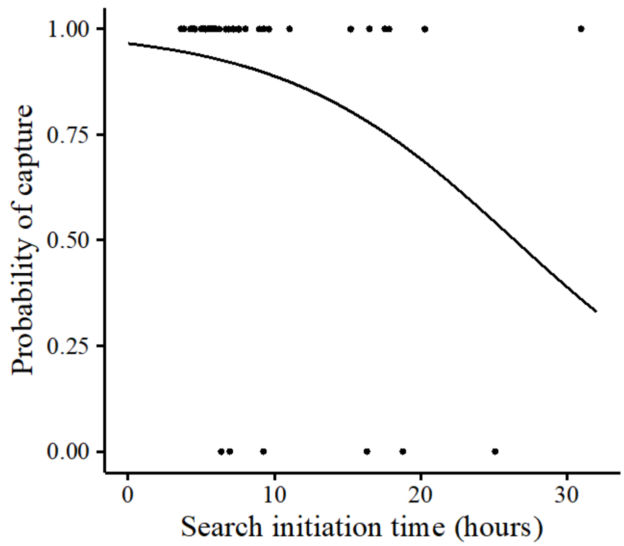

Figure 5. Probability of capture for neonate elk in east-central Utah (n = 52) in relation to search initiation time (the time elapsed between expulsion of a vaginal implant transmitter and initiating a search). The shaded area represents a 95% confidence interval. All attempted captures took place during 2019-2020.

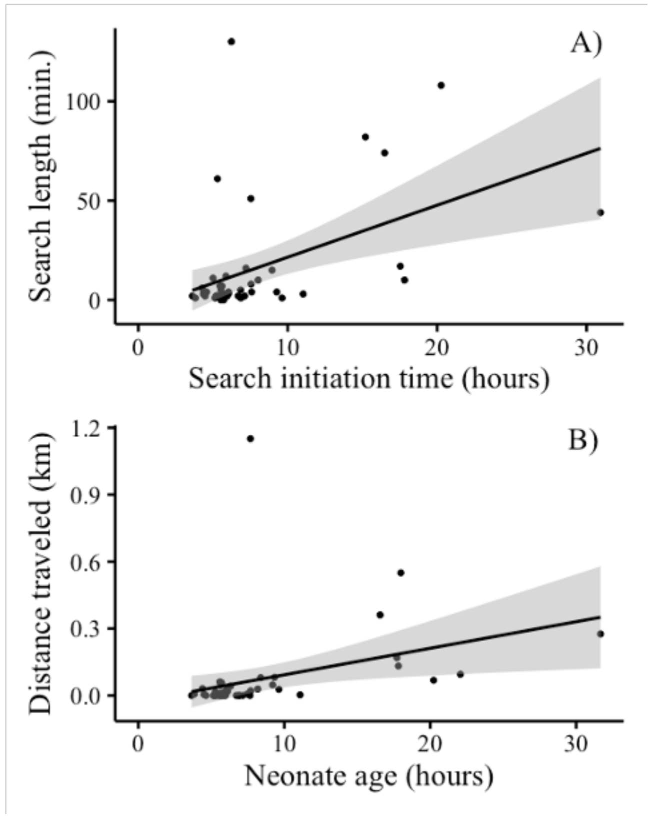

Figure 6. Data from captures of neonate elk in east-central Utah (n = 46). Vaginal implant transmitters were used to calculate search initiation time (the time elapsed between expulsion of a transmitter and initiating a search) and neonate age (expulsion of transmitter used as the estimated time of parturition). The shaded areas represent 95% confidence intervals. All captures took place during 2019-2020.