Using Vaginal Implant Transmitters to Aid in Capture of Mule Deer Neonates

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ABSTRACT Estimating survival of the offspring of marked female ungulates has proven difficult in free-ranging populations yet could improve our understanding of factors that limit populations. We evaluated the feasibility and efficiency of capturing large samples (i.e., >80/yr) of neonate mule deer (*Odocoileus hemionus*) exclusively from free-ranging, marked adult females using vaginal implant transmitters (VITs, $n =$ 154) and repeated locations of radiocollared females without VITs. We also evaluated the effectiveness of VITs, when used in conjunction with in utero fetal counts, for obtaining direct estimates of fetal survival. During 2003 and 2004, after we placed VIT batteries on a 12-hour duty cycle to lower electronic failure rates, the proportion that shed $\leq$3 days prepartum or during parturition was 0.623 (SE = 0.0456), and the proportion of VITs shed only during parturition was 0.447 (SE = 0.0468). Our neonate capture success rate was 0.880 (SE = 0.0359) from females with VITs shed $\leq$3 days prepartum or during parturition and 0.307 (SE = 0.0235) from radiocollared females without VITs or whose implant failed to function properly. Using a combination of techniques, we captured 275 neonates and found 21 stillborns during 2002–2004. We accounted for all fetuses at birth (i.e., live or stillborn) from 78 of the 147 females (0.531, SE = 0.0413) having winter fetal counts, and this rate was heavily dependent on VIT retention success. Deer that shed VITs prepartum were larger than deer that retained VITs to parturition, indicating a need to develop variable-sized VITs that may be fitted individually to deer in the field. We demonstrated that direct estimates of fetal and neonatal survival may be obtained from previously marked female mule deer in free-ranging populations, thus expanding opportunities for conducting field experiments. Survival estimates using VITs lacked bias that is typically associated with other neonate capture techniques. However, current vaginal implant failure rates and overall expense limit broad applicability of the technique. (JOURNAL OF WILDLIFE MANAGEMENT 71(3):945–954; 2007)

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Measuring fetal and neonatal deer survival as a function of dam characteristics (e.g., body condition, disease status) is necessary to understand components of reproductive ecology, population productivity, and disease transmission. Conducting such research in enclosure facilities is typically necessary to achieve experimental rigor, although important insights may be obtained by conducting similar research in free-ranging populations. For example, experimental studies that relate nutrition of female ungulates to reproductive success have been restricted largely to enclosures (Verme 1965, 1969; Robinette et al. 1973; Thorne et al. 1976; Cook et al. 2004). Applying similar experimental treatments to adult females in free-ranging populations, while quantifying neonatal production and survival, may provide an understanding of nutritional effects on these parameters relative to other potential limiting factors (e.g., predation, disease). Feasibility of such studies depends on whether necessary numbers of neonates can be captured exclusively from radiomarked females with known treatment status, at least whenever treatments are applied to individuals or groups rather than whole populations. Capturing neonates from previously marked females enables the relation of female-specific data to reproductive success, which has broad applicability for field studies if sample size objectives can be met.

Huegel et al. (1985) captured white-tailed deer (*Odocoileus virginianus*) neonates from radiocollared females in south-central Iowa, USA, by repeatedly locating each female during the fawning period and searching for fawns when successive locations indicated a reduction in daily movements. Carstensen et al. (2003) employed similar methods using a fixed-wing aircraft to obtain successive female locations but concluded the technique was inefficient and not viable for capturing large samples of white-tailed deer fawns in north-central Minnesota, USA. A fixed-wing location of radiocollared females combined with aerial fawn searches is a possibility in relatively open habitats but not in closed-canopy habitats (Hamlin et al. 1984). M. A. Hurley (Idaho Department of Fish and Game, personal communication) and T. M. Pojar (Colorado Division of Wildlife, personal communication) attempted to locate radiocollared mule deer (*O. hemionus*) females from the ground and conduct searches when female behavior or appearance indicated fawn(s) may be present, but such attempts were inefficient and not considered useful for capturing large samples of neonates.

The most promising technique employed to capture neonates from marked females is use of vaginal implant transmitters (VITs). Initial applications of VITs relied on vulvar sutures for transmitter retention, which were largely ineffective and raised animal welfare concerns (Garrott and

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Bartmann 1984, Giessman and Dalton 1984, Nelson 1984). More recently, modified VITs were used in white-tailed deer with better success (Bowman and Jacobson 1998, Carstensen et al. 2003). The modified VIT has flexible, silicone wings that induce pressure against the vaginal wall to retain the transmitter, thus eliminating sutures and facilitating a quick, nonsurgical insertion process. Other studies using newly designed VITs were recently conducted on Columbian black-tailed deer (*O. hemionus columbianus*; Pamplin 2003), mule deer (Johnstone-Yellin et al. 2006), and elk (*Cervus elaphus*; Vore and Schmidt 2001, Johnson et al. 2006). These studies did not document any detrimental effects to the adult females, fetuses, or neonates by use of VITs. In a study focused on animal welfare, Johnson et al. (2006) found that VITs in elk caused minimal tissue irritation and did not impact reproductive performance. Recent data indicate VITs are potentially a viable technique for locating and capturing neonates from radiomarked adult female deer shortly after parturition (Carstensen et al. 2003, Pamplin 2003, Johnstone-Yellin et al. 2006).

Vaginal implant transmitters could also permit measurement of fetal survival in free-ranging populations. Fetal survival estimates are needed in populations where stillborn mortality is known to occur but is poorly understood or quantified (Ricca et al. 2002, Pojar and Bowden 2004). Survival could be estimated by counting the number of fetuses in utero during winter and using VITs to document the fate of each fetus at parturition. However, each of a female's documented in utero fetuses would need to be accounted for at birth to represent a valid data point. Precision of the survival estimate would therefore depend on the proportion of birth sites located where the number of fawns observed equals the number of known fetuses.

An additional advantage of using VITs to capture neonates may be a reduction in sample bias when compared to capture techniques that rely on opportunistic fawn capture (White et al. 1972, Ballard et al. 1998, Pojar and Bowden 2004). These techniques are susceptible to bias because of unequal capture success among vegetation types, road densities, fawn ages, and stages of fawning. When using VITs, neonate captures should be more random as long as VIT signals are monitored with equal intensity during fawning and assuming the sample of radiocollared females was captured with minimal bias. Thus, VITs could have more broad applicability regardless of whether study objectives require that fawns be captured from previously marked females.

Our principal objective was to evaluate the feasibility of capturing large samples of newborn fawns exclusively from radiocollared adult females in a free-ranging, migratory mule deer population using a combination of 2 approaches: 1) VITs placed in adult female mule deer during winter as a mechanism for determining the timing and location of birth sites the following June and 2) repeated ground relocations of radiocollared females without VITs during the fawning period. Our secondary objectives were to evaluate the effectiveness of VITs for estimating fetal survival when used in conjunction with fetus counts and to provide an evaluation of VITs as a neonate capture technique for migratory mule deer in the Intermountain West, USA.

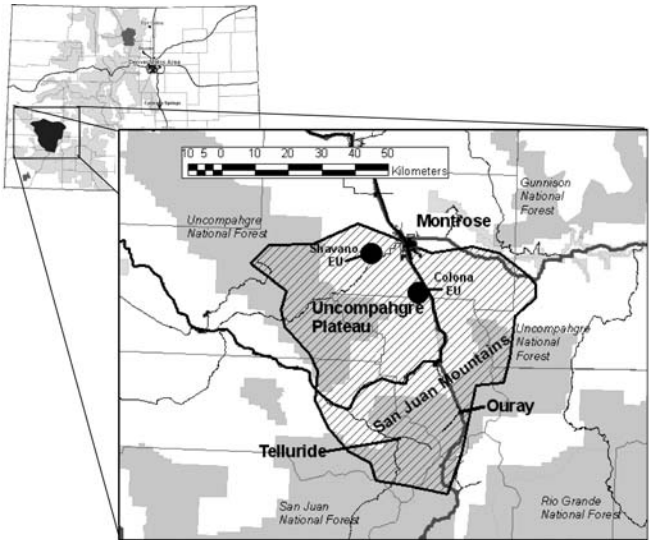

Figure 1. Location of winter range experimental units (EU; ●) and summer range study area (▨) on the Uncompahgre Plateau and adjacent San Juan Mountains in southwest Colorado, USA, where we studied vaginal implant transmitters in mule deer, 2002–2004.

STUDY AREA

We conducted our research in southwest Colorado, USA, on the southern half of the Uncompahgre Plateau and in the adjacent San Juan Mountains (Fig. 1). We restricted the winter range study area to 2 sites, or experimental units (EUs), to meet other research objectives (Bishop et al. 2004). For clarity, we defined the core of each EU as the area containing 90% of the radiocollared deer captured in that unit. The core of the Colona EU (38°21′N, 107°49′W) covered 12 km^2 and the core of the Shavano EU (38°27′N, 108°01′W) covered 22 km^2. Each EU encompassed approximately 40 km^2 when considering all radiocollared deer, ranging in elevation from 1,830 m to 2,290 m. Winter range EUs were comprised of pinyon (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) woodlands with interspersed big sagebrush (*Artemisia tridentata*) adjacent to irrigated agricultural fields. During our study, annual precipitation averaged 22.3 cm and the minimum temperature in January averaged −8.2° C in Montrose, Colorado (Western Regional Climate Center [WRCC] 2005), which is 60 m below the lowest winter range elevation in either EU. Deer occupied the winter range EUs from November through April each year. Estimated deer densities typically varied between 31 deer/km^2 and 59 deer/km^2 in the core of each EU during the study, with densities periodically reaching 85 deer/km^2 in portions of an EU (C. J. Bishop, Colorado Division of Wildlife, unpublished data).

We defined summer range based on migratory movements of radiocollared deer captured in the winter range EUs. Summer range for 95% of the radiocollared deer covered 2,500 km^2, whereas the total summer range encompassed approximately 4,000 km^2 between 37°49′N and 38°28′N latitude and 107°26′W and 108°17′W longitude (Fig. 1). Elevations ranged from 1,830 m to 3,500 m, with a majority of deer summering between 2,600 m and 3,000 m. Dominant summer range habitat types, from lower to higher elevations, were pinyon–juniper, Gambel oak (*Quercus gambelii*), ponderosa pine (*P. ponderosa*), big sagebrush, aspen (*Populus tremuloides*), and mixed forests of Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*). Diverse habitat mosaics occurred at interfaces of each of the major habitat types. Snowberry (*Symphoricarpos* spp.) was a common understory shrub in Gambel oak, ponderosa pine, and aspen habitats, and it occasionally occurred in sagebrush habitats. Annual precipitation averaged 57.4 cm and the maximum temperature in July averaged 26.7° C at a weather station in the summer range situated at 2,438 m elevation (WRCC 2005).

METHODS

Sample Size

We placed VITs in 154 pregnant adult mule deer during 26 February–2 March 2002–2004. During 2002, we placed VITs in 18 adult females in each EU as a pilot study to evaluate effectiveness of VITs relative to equipment functionality and logistical feasibility. We based sample size calculations on a success–failure analysis of VIT retention to parturition and the proportion of VITs resulting in a fawn capture. During 2003 and 2004, we attempted to insert VITs in 30 adult females in each EU each year. We based sample sizes on precision of resulting neonate survival estimates necessary to meet other research objectives (Bishop et al. 2004). We assumed 30 VITs would facilitate the capture of $\geq$40 fawns, when combined with opportunistic fawn captures from other radiocollared females during the fawning period.

We captured and radiocollared an additional 139 adult females that did not receive VITs during 20 November–14 December 2000–2003 (Bishop et al. 2004). We permanently attached radiocollars on all captured adult females; thus, many of the females were present in multiple years' samples. Most adult females receiving a VIT in a given year did not receive a VIT the following year, but we retained the females in the radiocollared sample if they survived to the next year. Our total samples of radiocollared females with VITs were 36, 58, and 60 during 2002, 2003, and 2004, respectively. Our total prefawning samples of radiocollared females without VITs were 85, 114, and 145 during 2002, 2003, and 2004, respectively.

Capture and Handling

We captured adult females during November and December primarily using baited drop nets (Ramsey 1968, Schmidt et al. 1978) and secondarily using helicopter net-gunning (Barrett et al. 1982, van Reenen 1982). We used helicopter net-gunning during late February and early March to capture all deer receiving VITs. We hobbled and blindfolded all deer prior to handling.

We ferried adult females receiving VITs $\leq$3.5 km by the helicopter to a central processing location. During February–March 2002, we chemically immobilized 12 deer in each EU immediately following net-gun capture using a combination of 5:1 ketamine (5–7 mg/kg) and xylazine (1–3 mg/kg) given intravenously to facilitate ultrasonography and insertion of VITs. Immediately prior to release, we reversed xylazine with an intravenous injection of yohimbine at a rate of approximately 12 mg/45 kg animal body mass. We physically restrained all other captured deer in each experimental unit during 2002, thereby evaluating the need for chemical restraint to perform the necessary handling procedures. We found that physical restraint alone worked well and therefore did not chemically immobilize deer during 2003 and 2004.

Following capture, we fitted adult females with vinyl-belted radiocollars equipped with mortality sensors (Lotek, Inc., Newmarket, ON, Canada; Advanced Telemetry Systems, Inc., Isanti, MN), which activated after remaining motionless for 4 hours. We stitched neck band material (Ritchey Mfg. Co., Brighton, CO) to the left side of each radiocollar, which we engraved with a unique, 2-symbol marking for visually identifying deer. We measured mass, hind foot length, and chest girth of each deer and estimated deer age using tooth replacement and wear (Severinghaus 1949, Robinette et al. 1957, Hamlin et al. 2000). During captures in February–March, we performed transabdominal ultrasonography using an Aloka 210 (Aloka, Wallinford, CT) portable ultrasound unit with a 3-MHz linear transducer to establish pregnancy status and measure fetal rates (Stephenson et al. 1995). We shaved the left caudal abdomen from the last rib and applied lubricant to facilitate transabdominal scanning. We fitted each pregnant deer with a VIT and released nonpregnant females without a radiocollar or VIT. We performed the ultrasound and VIT insertion procedures in a 4.3 × 4.9 m wall-frame tent to minimize disturbance from helicopter rotor wash and adverse weather conditions and to create a dim environment to facilitate ultrasonography.

Vaginal Implant Transmitters

We used VITs (M3930, Advanced Telemetry Systems), which have been described in detail elsewhere (Bowman and Jacobson 1998, Carstensen et al. 2003, Johnstone-Yellin et al. 2006). However, we made several noteworthy alterations. Antennas were precut by the manufacturer to 6 cm in length with antenna tips encapsulated in a resin bead to eliminate sharp edges. During 2003 and 2004, we placed VITs on a 12-hour on–off duty cycle to extend battery life. Immediately prior to deer capture, we initiated the duty cycle by removing magnets from the transmitters at 0430 hours, which caused the transmitters to become active at 0530 hours during the fawning period because of daylight savings time. Similar to others (Carstensen et al. 2003, Johnstone-Yellin et al. 2006), we used a temperature-sensitive switch that caused VITs to increase pulse rates from 40 pulses to 80 pulses per minute when the temperature dropped below 32° C. A temperature drop below 32° C was indicative of the VIT being expelled from the deer.

After we initiated the 12-hour on–off cycle, we sterilized VITs in a chlorhexidine solution, rinsed them with sterile saline solution, and allowed them to air-dry before sealing them in 7.6 × 20.3-cm sterile pouches. We inserted VITs using a clear, plastic swine vaginoscope (Jorgensen Laboratories, Loveland, CO) and alligator forceps. The vaginoscope was 15.2 cm long with a 1.59-cm internal diameter and had a smoothed end to minimize vaginal trauma. We measured lengths of adult mule deer vaginal tracts from road-killed deer obtained in the study area to gauge approximate insertion distance. We placed vaginoscopes and alligator forceps in cold sterilization containers with chlorhexidine solution between each use and we used a new pair of nitrile surgical gloves to handle the vaginoscope and VIT for each deer. To insert a VIT, we folded the silicone wings together and placed the VIT into the end of the vaginoscope. We liberally applied sterile K-Y Jelly® (Johnson and Johnson, New Brunswick, NJ) to the scope and inserted it into the vaginal canal until the tip of the VIT antenna was approximately flush with the vulva. We used the alligator forceps, which extended through the vaginoscope, to firmly hold the VIT in place while the scope was pulled out from the vagina. The transmitter antenna was typically flush with the vulva, but it occasionally extended up to 1 cm outward. All capture and handling procedures, including VIT techniques, were approved by the Colorado Division of Wildlife's Animal Care and Use Committee (project protocols 11–2000 and 1–2002).

Radiomonitoring and Neonate Capture

We monitored live–dead status and general location of all radiocollared females daily from the ground during winter and spring. We located each of the adult females with VITs using aerial telemetry every 2–3 weeks from March through May. During each morning of June we checked VIT signal status by aerially locating each radiocollared female having a VIT. We began flights at 0530 hours and usually completed them by 1000–1100 hours. Early flights were necessary to detect fast signals because temperature sensors of VITs expelled in open habitats and subject to sunlight often exceeded 32° C by midday, which caused VITs to switch back to a slow (i.e., prepartum) pulse. When we detected a fast (i.e., postpartum) pulse rate, we used very high frequency receivers and directional antennae from the ground to simultaneously locate the VIT and radiocollared female, which were typically in proximity to one another. We attempted to observe behavior of the collared female, establish whether the VIT was shed at a birth site, and search for fawns in the vicinity of the female and expelled VIT. In cases where the female had moved away from the VIT (i.e., >200 m), we located the VIT to determine whether shedding occurred at a birth site and whether any stillborn fawn(s) were present and subsequently located the collared female to search for fawns at her location. We attempted to account for each female's fetus(es) as live or stillborn fawns in order to quantify in utero fetal survival from February to birth. We classified each fawn found dead at a birth site as stillborn unless evidence was present to suggest the fawn was born alive. In most cases, we confirmed that the fawn had died before birth via laboratory necropsy. We wore surgical gloves when handling fawns to help minimize transfer of human scent.

We located most radiocollared females that did not receive VITs from the ground approximately every other day during June, relying on female behavior and searches in the vicinity of the female to locate fawns. We did the same for any VIT female whose implant failed because of premature expulsion or battery failure. We worked in pairs and partitioned the study area into segments, whereby each 2-person team was responsible for one segment. We used 3–4 teams during 2002 and 5–6 teams during 2003 and 2004.

Effectiveness of Vaginal Implant Transmitters

We assessed VIT effectiveness in terms of function, retention to parturition, and fawn capture success. We assigned the fate of each VIT to one of 7 categories: 1) censor, 2) migration loss, 3) battery or transmitter failure, 4) early prepartum shed (i.e., >3 d prepartum), 5) late prepartum shed (i.e., ≤3 d prepartum), 6) parturition shed within 200 m of the birth site, and 7) parturition shed at the birth site. We combined categories 6 and 7 for analysis because 92% of all parturition sheds were at the birth site or only several meters away. We censored VITs associated with prepartum female mortalities and missing females (i.e., unable to detect radiocollar signal) because these deer failed to provide an adequate test of VIT effectiveness. In each case, the VIT was functioning correctly when the female died or disappeared. There was no evidence to link VITs to the mortality events, which in most cases were caused by predation.

We considered migration losses, battery failures, and early prepartum sheds as VIT failures. Migration losses refer to VIT signals that disappeared during spring migration and represent either battery failures or early prepartum sheds between winter and summer range. In either event, we were unable to recover the VITs but lacked conclusive evidence to declare battery failures. We documented battery failures based on the disappearance of a female's VIT signal after having consistently heard the signal on a daily basis. We allocated ≥20 minutes of aerial searching around each female for 3 additional days before classifying a VIT as a battery failure. We confirmed 3 battery failures by opportunistically finding VITs when conducting ground searches for fawns in the vicinity of radiocollared females whose VITs had failed. In each case the VIT battery had failed.

We considered late prepartum sheds and parturition sheds as 2 levels of VIT success. We quantified the proportion of successful fawn captures associated with each level of VIT success, as well as the proportion of fawn captures from all non-VIT females and females with VIT failures. We describe effort associated with each type of fawn capture by calculating the number of person-hours per captured fawn. We describe costs associated with the 2 types of fawn capture by considering all operating and personnel expenses, including capture and transmitter costs for adult females.

We used constant rates of $450 per female for helicopter net-gunning expenses and $215 per transmitter (i.e., radiocollars and VITs) in our calculations. We also determined the expected reduction in fawn capture costs if all VITs had been successful.

We evaluated the utility of VITs for quantifying direct estimates of fetal survival by determining the number of females with VITs for which the number of postpartum fawns observed (live or stillborn) equaled the number of fetuses measured in February–March. Each fetus was indirectly marked via the radiomarked female, thereby allowing a direct binomial survival estimate. The sample would be more robust by including all females in which ≥ 1 fetus was accounted for at parturition and right-censoring the missing fetuses. However, in this application, censoring would bias fetal survival estimates upward because we typically located only live fawns when ≥ 1 fetuses were missing. Additionally, such censoring would necessitate assuming the fetuses never existed because we could not measure fetal survival as a function of time. This approach also assumes that no fetuses were resorbed, which appears reasonable for mule deer (Robinette et al. 1955, Medin 1976, Carpenter et al. 1984). We therefore considered the subset of females for which we recovered all fetuses at parturition as the viable sample for estimating fetal survival.

Deer Body Size and Implant Retention

We hypothesized that probabilities of VIT retention to parturition were related to deer behavior and morphology. We cannot easily modify the former whereas we could address the latter by manufacturing different sizes of the silicone wings used to retain the implant in the vaginal canal. Modifications to the silicone wings would be costly and require additional research and development to accommodate on-site field application of different-sized wings (C. O. Kochanny, Advanced Telemetry Systems, personal communication). We evaluated VIT retention as a function of deer morphometric variables and age using PROC LOGISTIC in SAS (SAS Institute 2003) to determine whether retention probabilities decreased for larger adult females. We used a binary response model where the 2 levels of VIT retention were synonymous with our success–failure definitions: 1) VIT retained until ≤ 3 days prepartum (i.e., retained) and 2) VIT shed >3 days prepartum (i.e., not retained). We then performed a second modeling analysis to distinguish between the 2 levels of successful retention; the binary levels of the response variable were 1) VIT retained to parturition (i.e., fully retained) and 2) VIT shed 1–3 days prepartum (i.e., partially retained). Independent variables were female mass (kg), chest girth (cm), hind foot length (cm), and age (yr). Ungulate mass and chest girth have been shown to be correlated (Weckerly et al. 1987, Cook et al. 2003). We used both variables in our analysis to provide a more complete evaluation of VIT retention and to avoid assumptions regarding which variable would be more informative. We only considered models with additive effects because we lacked a strong rationale for testing interactions among the variables. We evaluated model fit using the Hosmer–Lemeshow goodness-of-fit test (Hosmer and Lemeshow 2000). We performed model selection using Akaike's Information Criterion corrected for sample size (AIC_c; Burnham and Anderson 2002).

Potential Bias of Differing Fawn Capture Strategies

We caused minimal disturbance during the fawning period to adult females with successful VITs because we only located the females from the ground once or twice to capture their fawns. Conversely, we tracked a majority of non-VIT females every 1–3 days during June until we captured their fawns. We compared survival rates between fawns captured with the assistance of VITs and fawns captured opportunistically by repeatedly tracking radiocollared females. We analyzed survival through 6 months of age using a common entry date and incorporating right-censoring as appropriate (Kaplan and Meier 1958, Pollock et al. 1989).

On occasion, we found newborn fawns when we located a radiocollared female in the immediate vicinity of unmarked female(s). We did not place radiocollars on newborn fawns when the identity of the dam was in doubt. However, some probability existed for mistakenly capturing fawns from a nearby unmarked female. The probability was higher for fawns captured opportunistically following repeated locations of a collared female, as compared to successful VIT sheds where the timing and location of birth was known. We evaluated our success of capturing the correct fawns by subsequent observations of the radiocollared female and fawn(s) together and evaluating the return rate of surviving fawns to the correct winter range EU. For the latter analysis, we considered the sample of all radiocollared fawns that survived long enough to migrate to winter range and calculated the proportion that migrated to the correct winter range EUs.

RESULTS

Effectiveness of Vaginal Implant Transmitters

The proportion of all VITs that shed ≤ 3 days prepartum or during parturition was 0.565 (SE = 0.0410, n = 147), whereas the proportion of VITs shed during parturition was 0.401 (SE = 0.0406, n = 147). We censored VITs from 7 females; 5 died prepartum and 2 disappeared following spring migration. Of the remaining 147 VITs, we observed 7 migration losses, 23 battery failures, 34 early prepartum sheds, 24 late prepartum sheds, 5 parturition sheds within 200 m of the birth site, and 54 parturition sheds at the birth site. Of the battery failures, 16 of 23 occurred during 2002. Considering only data from 2003 and 2004, the proportion of VITs that shed ≤ 3 days prepartum or during parturition was 0.623 (SE = 0.0456, n = 114), and the proportion of VITs shed during parturition was 0.447 (SE = 0.0468, n = 114). During 2003–2004, we observed 4 censors, 7 migration losses, 7 battery failures, 29 early prepartum sheds, 20 late prepartum sheds, and 51 parturition sheds (48 at the birth site).

Our neonate capture success rate was 0.915 (SE = 0.0366, n = 59) for females with VITs shed during parturition and 0.792

(SE = 0.0847, n = 24) for females with VITs shed late prepartum. Combining both levels of VIT success (i.e., late prepartum and parturition sheds), our neonate capture success rate was 0.880 (SE = 0.0359, n = 83). Neonate capture success was 0.438 (SE = 0.0625, n = 64) for females with VIT failures and 0.282 (SE = 0.0251, n = 323) for all non-VIT, radiocollared females. We intensively located females with failed VITs from the ground because of our previous data investment (i.e., fetus counts and body condition measures) and to document the number of days VITs were prematurely shed by identifying timing of birth. Conversely, frequency of locations was more variable for non-VIT, radiocollared females during the fawning period, particularly those located on the fringes of the study area or in remote areas. Our overall neonate capture success rate based on repeated ground telemetry locations and corresponding fawn searches for all radiocollared females without VITs or where VITs were ineffective was 0.307 (SE = 0.0235, n = 387).

We captured 296 neonates (including stillborns) from radiocollared females during the study: 89 from females with VITs shed during parturition, 25 from females with VITs shed late prepartum, 43 from females with failed VITs, and 139 from females not receiving VITs. Daily capture crews during June included 6 individuals in 2002, 8 individuals in 2003, 9 individuals in 2004, and part-time assistance from 3–4 additional personnel during all years. Total person-hours also included 4–5 fixed-wing pilot-hours per day for VIT monitoring and occasional non-VIT female monitoring. We committed approximately 8,660 total person-hours to capture the 296 neonates, or an average of 29.3 person-hours per captured fawn. We required approximately 7 person-hours per captured fawn from females with parturition-shed VITs, 16 person-hours per captured fawn from females with VITs shed late prepartum, and 42 person-hours per captured fawn from females with failed VITs and females not receiving VITs. We attributed 75% of the pilot-hours toward fawns captured from females with successful VITs.

Considering all capture, transmitter, and personnel costs, we spent approximately $1,325 per fawn captured from females receiving VITs and $890 per fawn captured from females not receiving VITs. We used helicopter net-gunning to capture all females that received VITs whereas we used drop nets to capture most females that did not receive VITs, which partially explains the observed difference. If all females had been captured via net-gunning, the cost per fawn associated with non-VIT females would increase to approximately $1,200. Our estimate of $1,325 per fawn when using VITs included the 43 fawns captured from females with VIT failures. Our cost was $1,670 per fawn captured from females with successful VITs, which more appropriately reflects costs of VIT application in this study. If all VITs had been successful, our cost per captured fawn would reduce to approximately $860.

We accounted for all fetuses at birth (i.e., live or stillborn) from 78 of the 147 available females (0.531, SE = 0.0413) with in utero fetal measurements. Our ability to locate each of a female's fawns was heavily dependent on VIT success. We accounted for all fetuses from 0.780 (SE = 0.0544, n = 59) of females with VITs shed during parturition, 0.458 (SE = 0.104, n = 24) of females with VITs shed late prepartum, and 0.328 (SE = 0.0592, n = 64) of females with VIT failures.

Deer Body Size and Implant Retention

Our models of VIT retention to ≤3 days prepartum (χ^2_8 = 4.00, P = 0.857) and of VIT retention to parturition (χ^2_8 = 3.41, P = 0.906) adequately fit the data. We considered only 11 models in each analysis. Our model selection results provided strong evidence that VIT retention varied as a function of deer body mass and chest girth (Table 1). The probability of VIT retention decreased for larger deer. Mass and chest girth were highly correlated as expected (R^2 = 0.566). Mass explained the most variation in VIT retention to within 3 days of parturition (Table 1, Fig. 2). The beta estimate for mass based on the best model [VIT retention (mass)] was −0.0967 (SE = 0.0340). Mean mass of females shedding VITs early prepartum was 67.2 kg (SE = 1.24) whereas mean mass of females retaining VITs until ≤3 days prepartum was 63.0 kg (SE = 0.687). Chest girth explained the most variation in VIT retention to parturition, which distinguished between late prepartum and parturition sheds (Table 1, Fig. 3). The beta estimate for chest girth based on the best model [VIT retention (chest girth)] was −0.0923 (SE = 0.0542). The next best model [VIT retention (chest girth + age)] suggested an effect of age on VIT retention ($\hat{\beta}$ = −0.190, SE = 0.149, Table 1), indicating VIT retention to parturition decreased for older females. Mean chest girth was 96.8 cm (SE = 1.06) and mean age was 4.5 years (SE = 0.44) for females shedding VITs 1–3 days before birth, as compared to 94.7 cm (SE = 0.612) and 3.7 years (SE = 0.19) for females retaining VITs until parturition. In each analysis the intercept-only model received minimal AIC$_c$ weight (Table 1), providing additional evidence that the morphometric variables were important effects.

Potential Bias of Differing Fawn Capture Strategies

We found minimal evidence that capture strategy affected fawn survival. Survival of fawns captured from females with successful VITs ($S(t)$ = 0.558, SE = 0.0618, n = 104) was relatively similar (χ^2_1 = 1.51, P = 0.220) to survival of fawns captured through repeated locations of radiocollared females ($S(t)$ = 0.471, SE = 0.0458, n = 171).

Our rate of correctly capturing neonates from the targeted, radiocollared females based on fawn migrations to the appropriate winter range EUs was 0.947 (SE = 0.0196, n = 131). We incorrectly identified and radiocollared 7 fawns during the study, which included 2 sets of twins and 3 singletons. The 5 incorrect capture incidents occurred in high-density deer areas and involved 3 non-VIT females, a female with an early prepartum VIT shed, and a female with a late-prepartum VIT shed. In 2 cases, an uncollared adult female was present with the radiocollared female at the time of capture. We decided to radiocollar the neonate in each case, fully realizing the decision was debatable, based on behavioral cues of the radiocollared female. These were the only 2 incidents in the study where we opted to radiocollar

Table 1. Model selection results, based on Akaike's Information Criterion with small sample size correction (AIC$_c$), for evaluating vaginal implant transmitter (VIT) retention in adult female mule deer using logistic regression as a function of deer mass (kg), chest girth (chest; cm), hind foot length (foot; cm), and age (yr) in southwest Colorado, USA, 2002–2004.

Dependent variable[a]	Model	No. parameters	AIC$_c$	ΔAIC$_c$	Akaike wt
VIT retention to $\leq$3 d prepartum	Mass	2	135.9	0.00	0.30
	Mass, chest	3	137.1	1.18	0.17
	Chest	2	137.7	1.79	0.12
	Mass, age	3	137.8	1.92	0.12
	Chest, age	3	138.1	2.23	0.10
	Mass, chest, age	4	138.9	3.02	0.07
	Mass, chest, foot	4	139.0	3.07	0.06
	Age	2	140.9	5.00	0.02
	Mass, chest, foot, age	5	140.9	5.03	0.02
	Intercept only	1	143.1	7.15	0.01
	Foot	2	143.6	7.64	0.01
VIT retention to parturition	Chest	2	97.7	0.00	0.28
	Chest, age	3	98.3	0.56	0.21
	Mass, chest, age	4	99.1	1.40	0.14
	Mass, chest	3	99.5	1.76	0.12
	Age	2	100.3	2.62	0.08
	Mass, chest, foot, age	5	101.3	3.61	0.05
	Mass, chest, foot	4	101.7	3.96	0.04
	Intercept only	1	101.9	4.15	0.03
	Mass, age	3	102.5	4.77	0.03
	Foot	2	103.1	5.38	0.02
	Mass	2	103.3	5.55	0.02

[a] We present 2 model selection analyses; we define levels of the binary response variable, VIT retention, differently in each analysis. In the first analysis, the 2 levels of VIT retention are 1) retained (i.e., VIT retained to $\leq$3 d of parturition) and 2) not retained (i.e., VIT shed >3 d prepartum). In the second, the levels of VIT retention are 1) fully retained (i.e., VIT retained to parturition) and 2) partially retained (i.e., VIT shed 1–3 d prepartum).

neonates when $\geq$1 female was present. With the exception of these 2 questionable incidents, our rate of capturing the correct neonates from our targeted females was 0.961 ($SE = 0.0171$, $n = 129$).

DISCUSSION

We found VITs to be an effective technique for capturing mule deer fawns from targeted, radiocollared adult females. We captured fawns from 88% ($SE = 3.59$) of adult females expelling VITs within 3 days of parturition. Similarly, Carstensen et al. (2003) reported 89% neonate capture success for white-tailed deer with VITs expelled at or near birth sites. Following technique improvements, Pamplin (2003) reported 61% capture success for black-tailed deer with VITs expelled at birth sites in thick vegetative cover. The main disadvantage of VITs was the inefficiency associated with a relatively high failure rate, which has been a common issue in studies of free-ranging deer (Bowman and Jacobson 1998, Carstensen et al. 2003, Johnstone-Yellin et al. 2006). The 2 main causes of VIT failures in our study were battery failures and early prepartum sheds. We greatly

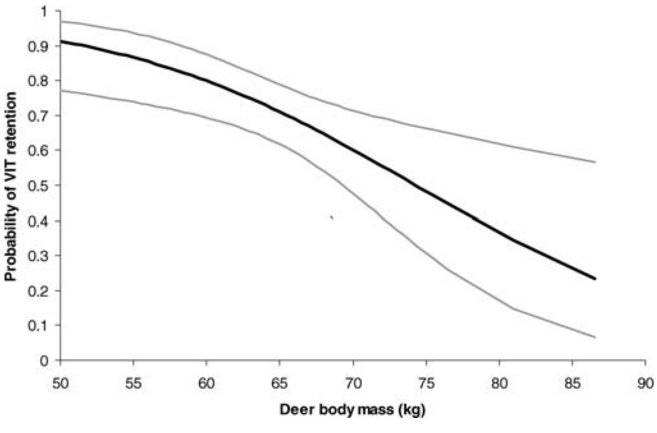

Figure 2. Estimated probability and 95% confidence interval of adult female mule deer retaining vaginal implant transmitters (VITs) until $\leq$3 days of parturition as a function of deer body mass, southwest Colorado, USA, 2002–2004. The underlying dataset includes all deer receiving VITs during late February or early March, except those with VITs that were never recovered due to battery failure or transmitter loss.

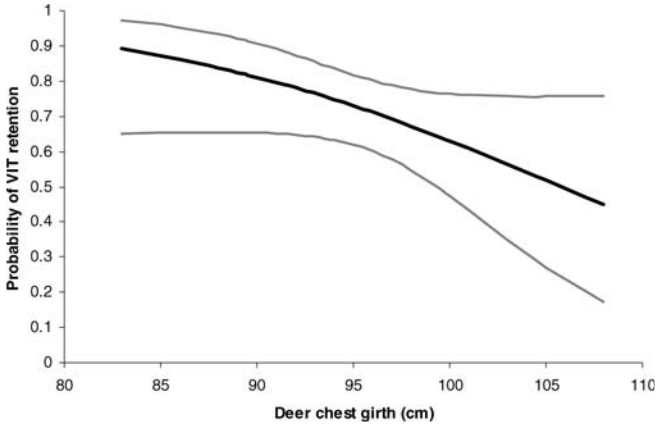

Figure 3. Estimated probability and 95% confidence interval of adult female mule deer retaining vaginal implant transmitters (VITs) to parturition as a function of deer chest girth, southwest Colorado, USA, 2002–2004. The underlying dataset includes only those deer retaining VITs until $\leq$3 days of parturition (i.e., successful VITs), thereby distinguishing between deer shedding VITs 1–3 days prepartum versus deer shedding VITs at parturition.

reduced battery failures by incorporating a 12-hour duty cycle, and we found evidence that early prepartum VIT sheds were a function of deer body size. The latter indicates a need to manufacture variable-sized silicone retention wings that may be fitted to deer much in the same way radiocollars are individually fitted. The future applicability of VITs may depend on how well subsequent VIT modifications lower the failure rate, which could reduce overall expense of the technique by as much as half. Aside from specific applications such as capturing fawns from target females, VITs could be applied broadly to facilitate random neonate capture spatially and temporally, thereby minimizing sample bias that is innate to most other capture techniques.

Neonate captures associated with VITs were spatially random in the sense that adult females captured on winter range determined neonate capture locations instead of road access or vegetation type. We maintained this spatial randomness during fawning by aerially monitoring all VIT signals with equal effort regardless of deer location. Other neonate capture techniques (White et al. 1972, Hamlin et al. 1984, Ballard et al. 1998, Pojar and Bowden 2004) have likely led to collared fawn samples that were biased towards roads, open habitats, or both. Vaginal implants facilitated temporal randomness at both the individual level (i.e., capturing fawns as newborns rather than as older, mixed-aged fawns) and population level (i.e., capturing a representative sample of fawns from the beginning to end of fawning).

Nearly all fawns captured from females with VITs shed during parturition were <2 days old and 75% were ≤ 1 day old. Biases arise when older fawns are captured because early mortality is missed (Pamplin 2003, Pojar and Bowden 2004). We captured several newborn fawns during the first week of June and again during the first 2 weeks of July, and we had 3 VITs remain in deer until late July indicating the respective females had not yet given birth. Similarly, Johnstone-Yellin et al. (2006) observed 2 of 19 captive females give birth in early–mid July. When other techniques are used (e.g., opportunistic fawn searches), capture periods typically end when a target sample has been captured or a point of diminishing returns is reached, neither of which fosters a representative sample of late-born fawns nor an accurate understanding of the proportion of adult females conceiving late in estrous or during a second estrous. Finally, we demonstrated that VITs can be used to directly measure fetal survival in free-ranging populations. Vaginal implants facilitated an optimal neonate sampling approach and could therefore be considered a preferred capture strategy even in situations where adequate samples of fawns have been captured using other techniques. Additional benefits of using VITs include measurements of birth site characteristics and deer fidelity to birth sites. Current failure rates and expense remain limiting factors to widespread application.

We demonstrated that large samples of fawns can be captured from radiocollared adult females via repeated ground locations and associated searches during the fawning period. Prior to this research, communications with peers and our own past experiences suggested this approach would not be successful over large areas of forest–shrub habitats in the Intermountain West; we have shown that such efforts can be successful with adequate technology and personnel. Overall capture costs associated with this technique were less than those associated with VITs even though personnel costs were much higher. Vaginal implants were expensive because of observed failure rates and annual costs to redeploy them. Conversely, we accumulated radiocollared adult females without VITs over the course of the study at comparatively minimal expense, thereby creating a large pool of fawns available for capture. We only met our neonate sample size objectives by combining the use of both capture techniques, which has important implications for any research where there is an advantage to capturing fawns from previously marked adult females. The necessity of capturing fawns by repeatedly locating collared females will diminish as VIT failure rates are reduced. Even so, neonate capture via ground telemetry of radiocollared adult females affords a viable opportunity to bolster sample sizes of neonates from target females.

We did not detect a difference in survival between fawns captured from females with successful VITs and fawns captured from females through repeated ground telemetry. Although we had large samples (i.e., >100/group), we lacked power to detect a small but biologically significant difference (e.g., $<10\%$). The point estimate for survival of fawns captured with VITs was higher than that for fawns captured without VITs, which should lessen potential concerns regarding impacts of VITs on fawn survival. Aside from the physical intrusion of the implant itself during gestation, VITs were beneficial by requiring only 1 or 2 site visits to capture fawns during the fawning period as opposed to repeated site visits and associated female disturbances.

Vaginal implants enhanced our ability to capture the correct fawns from target females. Overall, we correctly associated 96% of fawns with target females when excluding 2 questionable incidents that were not representative of neonate capture in our study. Although parturient females typically isolate themselves from other deer (Downing and McGinnes 1969, Robinette et al. 1977, Ozoga et al. 1982, Schwede et al. 1993), we occasionally observed ≤ 3-day-old fawn(s) together with ≥ 2 females, thereby making it difficult to determine which fawns belonged to which female.

MANAGEMENT IMPLICATIONS

We demonstrated that VITs can be used in conjunction with repeated locations of radiocollared adult females during fawning to capture large samples of neonates exclusively from marked deer, which expands opportunities for conducting experimental studies of free-ranging migratory deer populations. Direct estimates of fetal survival may be obtained by combining in utero fetal counts with VITs. Current VIT failure rates and overall expense limit applicability of the technique to well-funded studies with adequate personnel. Nevertheless, VITs have broad applicability for use in capturing random samples of neonates and generating unbiased estimates of neonate survival. Additional design modifications of VITs should incorporate different-sized silicone retention wings that may be fitted to individual deer to minimize premature expulsion of VITs.

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