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Tools and Technology

Techniques for Capturing Bighorn Sheep Lambs

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ABSTRACT Low lamb recruitment is a major challenge facing managers attempting to mitigate the decline of bighorn sheep (*Ovis canadensis*), and investigations into the underlying mechanisms are limited because of the inability to readily capture and monitor bighorn sheep lambs. We evaluated 4 capture techniques for bighorn sheep lambs: 1) hand-capture of lambs from radiocollared adult females fitted with vaginal implant transmitters (VITs), 2) hand-capture of lambs of intensively monitored radiocollared adult females, 3) helicopter net-gunning, and 4) hand-capture of lambs from helicopters. During 2010–2012, we successfully captured 90% of lambs from females that retained VITs to $\leq$1 day of parturition, although we noted differences in capture rates between an area of high road density in the Black Hills (92–100%) of South Dakota, USA, and less accessible areas of New Mexico (71%), USA. Retention of VITs was 78% with pre-partum expulsion the main cause of failure. We were less likely to capture lambs from females that expelled VITs $\geq$1 day of parturition (range = 80–83%) or females that were collared without VITs (range = 60–78%). We used helicopter net-gunning at several sites in 1999, 2001–2002, and 2011, and it proved a useful technique; however, at one site, attempts to capture lambs led to lamb predation by golden eagles (*Aquila chrysaetos*). We attempted helicopter hand-captures at one site in 1999, and they also were successful in certain circumstances and avoided risk of physical trauma from net-gunning; however, application was limited. In areas of low accessibility or if personnel lack the ability to monitor females and/or VITs for extended periods, helicopter capture may provide a viable option for lamb capture. © 2013 The Wildlife Society.

KEY WORDS bighorn sheep, capture, helicopter, lambs, neonates, netgun, *Ovis canadensis*, vaginal implant transmitter.

During the late 19th and early 20th centuries, bighorn sheep (*Ovis canadensis*) populations declined dramatically. These declines have been attributed to a wide array of factors, including diseases, unregulated hunting, loss of habitat, and competition with other ungulate species (Buechner 1960, Capp 1968, Spraker et al. 1984, Beecham et al. 2007, Wehausen et al. 2011). Over the years, trap-and-transplant efforts were successful in increasing the overall number of bighorn sheep throughout the Western North America, but many of the herds remain small and isolated (Douglas and Leslie 1999, Beecham et al. 2007). Additionally, periodic pneumonia epizootics have occurred in many herds, resulting in significant losses to populations. These die-offs are often followed by years of depressed lamb recruitment, which limits population recovery (Woodard et al. 1974, Spraker et al. 1984, Gross et al. 2000, Monello et al. 2001, Cassirer and Sinclair 2007). Identifying the underlying cause(s) for this poor recruitment is one of the major challenges facing bighorn sheep managers.

One of the difficulties inherent in understanding the causal mechanisms associated with poor recruitment and developing effective mitigating strategies is the inability to readily capture and monitor bighorn sheep lambs. Bighorn lamb

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capture is problematic because of the rugged and inaccessible terrain typically used for lambing and rearing of young (Shackleton et al. 1999). To date, lambs have been successfully captured in only a few studies. In Alberta, Canada, researchers used corral traps baited with salt to attract and capture adult females and lambs throughout the year (Samson et al. 1987, Festa-Bianchet 1988, Portier et al. 1998), and Scotton and Pletscher (1998) employed helicopter techniques to capture neonatal Dall sheep (*Ovis dalli*). However, most researchers examining lamb survival and juvenile recruitment have relied on intensive monitoring of marked females to determine whether lambs were at-heel or lamb:female ratios in the herd (Woodard et al. 1974, Wehausen et al. 1987, Cook et al. 1990, Cassirer and Sinclair 2007, Sirochman et al. 2012). The latter is particularly problematic because it may inaccurately reflect lamb survival resulting from the confounding effects of detection probability, female mortality, changing group associations, and lack of knowledge of female age-structure (Festa-Bianchet 1992, Jorgenson 1992, Bodie et al. 1995, Festa-Bianchet et al. 1996, Shackleton et al. 1999). Reliance on these metrics severely limits the identification of the timing and causes of lamb mortality.

The difficulty in capturing lambs also limits the ability of managers to assess the effectiveness of various efforts, such as the administration of antibiotics or vaccines, that are aimed at reducing the impacts of periodic pneumonia epizootics and improving lamb survival (Mcadoo et al. 2010, Wolfe et al. 2010, Sirochman et al. 2012). As a consequence, effective methods of capturing bighorn lambs are needed to study and devise improved management strategies for recovering bighorn sheep populations negatively impacted by poor lamb survival.

Here we describe and compare 4 techniques used to capture bighorn sheep lambs that have been employed in several regions across western North America. First, we examined the use of vaginal implant transmitters (VITs) in radio-collared females in combination with intensive monitoring and hand capturing of neonatal lambs. This technique has been successfully used to capture a variety of neonates of other ungulate species because the VIT is designed to remain with the female until parturition, at which time it exits the female and then emits a "deployed" signal (Carstensen et al. 2003; Johnson et al. 2006; Bishop et al. 2007, 2011). Secondly, we examined the utility of hand-capture of neonatal lambs born to radiocollared females that were intensively monitored. Third, we evaluated a helicopter net-gunning method (Schemnitz 2005) to capture 4 to 6-week-old lambs in several regions. Lastly, we investigated the use of hand-capture of lambs using a helicopter. We detail the strengths and limitations of each of these methods and provide an estimate of associated costs with each technique.

STUDY AREAS

Neonatal Capture

New Mexico: Peloncillo Mountains.—The study area for this project was located in the central Peloncillos in the southwestern corner of New Mexico, USA, and contained approximately 8,300 ha of bighorn sheep habitat. Peak elevations ranged from 1,512 m to 2,112 m above mean sea level (msl). Sandoval (1982) described 7 land-cover types in the Peloncillo Mountains: grass–desert scrub (40%), mixed shrub–grass (27%), desert shrub (12%), grassland (11%), pinyon–juniper (*Pinus edulis* and *Juniperus* spp.; 7%), oak (*Quercus* spp.; 3%), and mountain scrub (<1%). Climate in the Peloncillos was characterized by a monsoon precipitation cycle, with an average precipitation of 5 cm of rain/month during the July to September monsoon season. Average annual precipitation was 28 cm. Temperatures ranged from an average maximum temperature of 35° C in June to an average minimum of −3° C in December. Climate values were based on data collected at the Animas, New Mexico weather station from 1923 to 2012 (Western Regional Climate Center 2013).

South Dakota: East-central Black Hills.—The Black Hills are located in southwestern South Dakota and eastern Wyoming, USA. The study area for this project was located in the east-central portion of the Black Hills with bighorn sheep habitat encompassing an area of approximately 26,000 ha. Elevations ranged from 973 m to 2,202 m above msl. Ponderosa pine (*Pinus ponderosa*) forest comprised 83% of the landscape (USGS Gap Analysis Program 2013). Mixed-grass prairie (5%), riparian (4%), aspen (*Populus tremuloides*)–mixed-conifer forest (3%), and developed open space (2%) were other major land-cover types present in our study area (USGS Gap Analysis Program 2013). Average annual precipitation was 53 cm. Mean temperatures ranged from a maximum of 28° C in July to a minimum of −10° C in January. Climate values were based on data collected at the Hill City, South Dakota, weather station from 1981 to 2010 (National Oceanic and Atmospheric Administration [NOAA] 2013).

Helicopter Capture

Colorado: Pikes Peak.—The Pikes Peak study area was located west of Colorado Springs, Colorado, USA, and contained approximately 25,000 ha of bighorn sheep habitat. Elevations ranged from approximately 2,500 m to 4,300 m above msl. Bear and Jones (1973) provide a detailed description of the range of this herd.

Major land-cover types within this bighorn sheep range were ponderosa pine forest (33%), spruce–fir forest (29%), aspen stands (16%), mixed tundra (15%), and subalpine meadows (4%; USGS Gap Analysis Program 2013). Average annual total precipitation for the region was 60 cm. Average annual temperatures for the region ranged from a maximum of 22° C in July to a minimum of −14° C in January. Climate values were based on data collected at the Ruxton Park, Colorado, weather station from 1959 to 2012 (Western Regional Climate Center 2013).

New Mexico: Fra Cristobal Mountains.—The Fra Cristobal Mountains are located in South-central New Mexico, USA. The range contained approximately 12,000 ha of bighorn sheep habitat, and elevations ranged from 1,400 m to 2,109 m above msl. The study area was dominated by

Apacherian–Chihuahuan semi-desert grassland and steppe (84%), Chihuahuan creosotebush (*Larrea tridentata*), mixed desert and thorn scrub (10%), and Madrean pinyon–juniper woodland (3%) land-cover types (USGS Gap Analysis Program 2013). Climate in the Fra Cristobal Mountains was characterized by a monsoon cycle with an average precipitation of 4 cm/month falling in the wettest months of July and August. Average annual precipitation was 24 cm. Mean temperatures ranged from a maximum of 34° C in July to −2° C in January. Climate values were based on data collected at Elephant Butte Dam, New Mexico, from 1908 to 2012 (Western Regional Climate Center 2013).

South Dakota: Custer State Park.—In Custer State Park, South Dakota, USA, the 2 bighorn sheep sub-herds (East End and West End) resided in the approximately 430-ha French Creek Canyon. The elevation throughout the study area ranged from 1,127 m to 1,524 m above msl. Major land-cover types of this bighorn sheep range were ponderosa pine forest (80%), deciduous trees (11%), and grasslands (5%; USGS Gap Analysis Program 2013), interspersed with steep cliffs. Average annual precipitation was 50 cm. Average annual temperatures ranged from an average maximum of 27° C in July to a minimum of −9.4° C in December. Climate values were based on data collected at the Custer, South Dakota weather station from 1981 to 2010 (NOAA 2013).

METHODS

Neonatal Capture

Female capture.—At both sites in New Mexico, adult females were captured via net-gunning during winter months, while in the East-central Black Hills of South Dakota we captured adult females using a drop-net baited with weed-free alfalfa hay or using chemical immobilization (BAM: 0.43 mg/kg butorphanol, 0.29 mg/kg azaperone, 0.17 mg/kg medetomidine; Wildlife Pharmaceuticals, Windsor, CO) via dart rifle (Dan-Inject, Børkop, Denmark).

VIT deployment.—In the Peloncillos and the Black Hills, we used PETTMPF2 or M3930 VITs manufactured by Advanced Telemetry Systems (ATS; Isanti, MN) with a redesigned wing system and antenna length of 6 cm (Bishop et al. 2011). Prior to VIT deployment, pregnancy status of females was checked via ultrasonography at the time of capture. Females that were not pregnant or not checked for pregnancy at the time of capture were not fitted with VITs. Methods of VIT deployment followed Bishop et al. (2011). In addition to receiving VITs, all females were fitted with very high frequency (VHF) collars (ATS) that were uniquely marked to facilitate individual identification.

Lamb capture using females with VITs.—Prior to the lambing season, radiocollared females were monitored 1–3 times/week from the ground using hand-held directional antennas (Telonics, Inc., Mesa, AZ), or from a Cessna 182 (Cessna Aircraft Co., Wichita, KS) airplane. We listened for possible VIT expulsion each time we located females. When we detected an expelled VIT prior to the lambing season, we retrieved it using ground telemetry and ascertained whether the female had aborted the fetus on-site, and estimated date of expulsion as the mean date between the first mortality signal and the last active signal received.

During the lambing season in the Peloncillo Mountains of New Mexico, females with VITs were checked each morning and evening to account for daytime temperatures sufficiently warm to affect the temperature sensor in the VIT, and cause its pulse rate to return to an "undeployed mode." When the expulsion of a VIT was indicated and the precise event transmitter (a component of the PETTMPF2 model VITs that emits a series of single or double beeps that can be used to calculate the amount of time the VIT has been expelled to within 0.5 hr) indicated that a lamb was <3 hours old, we waited until it was >3 hours old to avoid interrupting mother–young bonding, which could result in abandonment (Livezey 1990). When the precise event transmitter indicated that the lamb was >3 hours old, we immediately attempted to visually locate the associated female through a spotting scope (Nikon Corporation, Tokyo, Japan) from a distance that would minimize disturbance. We observed the female's behavior and visually searched for a lamb in her vicinity. If a lamb was not seen, we continued to focus our efforts on the location of the female. One person monitored the female (and lamb if detected) through the spotting scope, while a 2-person team approached the female and/or lamb. The team used telemetry equipment and guidance from the person with the spotting scope to locate the female and/or lamb.

During the lambing season in the Black Hills of South Dakota, we employed a similar protocol. Females with VITs were checked once daily during the lambing season to determine whether the VIT had been expelled. If the radio signal indicated a VIT had been expelled and terrain permitted, personnel would use telemetry to home in on the expelled VIT on foot and retrieve it.

At both study sites, if the VIT was located at a birth site and the lamb was present, we attempted to hand-capture it. If the dam had moved away from the VIT or if a lamb was not located in the vicinity of the female, we searched the area surrounding the female's location and the VIT location, and if a lamb was located we attempted capture. In the event the VIT was prematurely expelled based on a lack of evidence of birthing activities at the VIT site and observation of the female without a lamb, we intensively monitored the individual female's behavior. If we subsequently established the female had lambed, we attempted to capture the lamb once it was observed.

Lamb capture using females without VITs.—In the Fra Cristobal Mountains of New Mexico and the Black Hills of South Dakota, we monitored radiocollared females without VITs on a near daily basis for movement patterns indicative of parturition and presence of newborn lambs via radio-telemetry and visual observation from a distance. When we detected a newborn lamb, we assessed its degree of mobility by observations of ambulatory movements. We attempted hand-capture from the ground if the lamb appeared sufficiently immobile and the terrain was accessible. We waited until the animals bedded down before attempting capture. Solitary female–lamb pairs were preferred; however, we also attempted captures of lambs associated with small groups of females. Once animals bedded down, we noted the location of the animals in relation to topography and notable landmarks. Ideally, while attempting to avoid detection (e.g., by climbing up the opposite side of a ridge), 2 people approached the animals from above. When detection by the animals was imminent, we rapidly approached the animals' location, causing the female to flee, and the lamb would hide or attempt to flee. We would conduct a short search or chase to capture the lamb.

Lamb handling and marking.—We physically restrained each captured lamb, blindfolded, and fitted the lamb with an expandable, 62-g VHF collar equipped with a 6-hour mortality switch (Model M4210; ATS) or an expandable, 83-g VHF collar equipped with a 2-hour mortality switch (MOD-305; Telonics, Inc.). Additionally, sex, age, and weight data were collected from captured lambs. We monitored lamb survival after capture using telemetry to determine whether lambs may have died or were abandoned as a result of our capture activities. We strived to keep handling time to <5 minutes.

Helicopter Capture

Net-gun.—We used 3 companies for helicopter capture work. Hawkins & Powers Aviation (Greybull, WY) captured lambs in Custer State Park and the Fra Cristobals Mountains. Helicopters by Oz (Marysvale, UT) also captured lambs in the Fra Cristobal Mountains, and Quiksilver Air, Inc. (Fairbanks, AK) attempted captures at Pikes Peak. The capture companies used a MD500D helicopter (MD Helicopters, Inc., Mesa, AZ) in South Dakota, and a MDHC500D in Colorado. In the Fra Cristobal Mountains, Helicopters by Oz used a Hughes 500 helicopter (Hughes Helicopters, Culver City, CA) and Hawkins & Powers Aviation used a Bell 206 JetRanger (Bell Helicopter Textron, Hurst, TX).

In Colorado, to minimize helicopter search time, we used radiotelemetry to locate groups of radiocollared females ($n = 23$), collared as part of a separate study. During capture activities in all study areas, the helicopter would approach a group of bighorn sheep containing lambs and gently haze animals into terrain suitable for capture. The gunner would then attempt to fire a 4×4-m nylon net with 10-cm mesh over the targeted lamb using either a hand-held or skid-mounted net-gun (CODA Enterprises, Inc., Mesa, AZ). Only one lamb was targeted, and females and lambs were not captured together. If a lamb was successfully netted, the helicopter would move >500 m away and land; capture personnel would immediately restrain the lamb via hobbles, collect biological samples of interest, and radiocollar the lamb using either a 68-g expandable neonate collar (M4210; ATS; Pikes Peak) or a 83-g expandable, breakaway MOD-305 transmitter on a CB-6 collar (Telonics, Inc.; Custer State Park; Fra Cristobal Mountains). After a maximum of 5 minutes of hazing, we abandoned capture efforts of bighorn sheep that could not be hazed from or that moved into rugged terrain unsuitable for capture. We monitored all collared lambs post-capture to determine abandonment or capture-related mortality rates.

Hand-capture.—We used Helicopters by Oz with a Hughes 500 helicopter for all helicopter hand-captures. In addition to the pilot, 2 people were aboard the helicopter that had its doors removed. Radio contact was maintained between the pilot and capture crews on the ground. Ground crews attempted to visually locate female and lamb groups prior to capture. The helicopter was equipped with antennas and a receiver to locate radiocollared females known to have lambs. We attempted to gently haze sheep into accessible terrain, and limited our hazing and chase time to ≤ 5 minutes.

If a lamb became separated from a group and tried to hide against a sheer rock face or boulder, the capture crew exited the helicopter one at a time by stepping onto the skid, and jumped or stepped to the ground. The capture crew approached the lamb from 5 m to 10 m in front of the cliff from different angles. When the lamb tried to flee, handlers attempted to manually restrain it. If a lamb was successfully captured, the helicopter would move >500 m away and land, and the lamb would be handled as described previously.

Animal handling was approved by the Institutional Animal Care and Use Committees at South Dakota State, New Mexico State Universities, Colorado Parks and Wildlife and University of Washington (SDSU, Approval no. 09-019A; NMSU, Approval no. 2011-026, CPW, ACUC-04-2011; UW, ACUC 3165-01).

Cost Estimates

We estimated the yearly and average costs to capture and radiocollar a lamb in each of 2 years using our various lamb-capture techniques. We recognize that capture costs will vary based on individual location and logistics. Our intent is for these estimates to serve as a basis of comparison only, and provide managers with a useful example of important cost considerations. We made several assumptions to permit cost estimation. First, we assumed annual female capture was necessary when capturing lambs from females fitted with VITs, but only necessary for the first year when capturing lambs from intensively monitored radiocollared females. For techniques requiring female capture, we used average capture success and survival rates of radiocollared females observed in our study to determine the average number of female captures needed to permit lamb capture during both years. Lastly, we assumed, if radiocollared females were not present in the study area, location of lambing areas were known well enough such that minimal time was spent searching for females with lambs. We estimated the costs of darting, drop-netting, and helicopter net-gunning females as follows: for darting females, we estimated the cost as US\$180/female, representing mainly the cost of capture drugs (BAM) with the assumption that, on average, 1.5 darts are required to capture one female, and assumed the use of agency personnel; for drop-netting, we estimated the cost as US\$125/female, which covers the cost of 10 technicians/day to conduct the capture (costs may be less if agency personnel were used in lieu of technicians); for helicopter net-gunning we estimated a cost of US$700/female for helicopter time. For all capture techniques discussed above, there is an additional cost of approximately US$225 for each VIT and for each radiocollar.

For capturing lambs, we estimated a cost of US$700/lamb for helicopter net-gunning, and a cost of US$900/lamb for helicopter hand-capture. The latter cost was higher because of the greater likelihood of unsuccessful capture attempts with helicopter hand-capture of lambs. Lastly, to estimate and compare the cost of monitoring radiocollared females fitted with VITs versus females without VITs and lacking detailed monitoring effort estimates, we used estimates provided by Bishop et al. (2007) for fawn capture. They found that 7 person-hours/captured fawn were required for does fitted with VITs versus 42 person-hours/fawn for females with failed VITs and females without VITs. These estimates seemed to provide a reasonable minimum estimate for lamb capture and provided a basis for comparison. We combined these effort estimates with an average cost of US $20/hour (e.g., technician, vehicle mileage) to provide the total cost of monitoring radiocollared females. We did not include the salary of agency personnel for any of the capture techniques, but included a cost of US$225/lamb for lamb radiocollars for all techniques.

RESULTS

Neonatal Capture

New Mexico: Peloncillo Mountains.—In early November 2011, 20 pregnant adult females were collared and fitted with VITs and translocated to the Peloncillo Mountains from the Fra Cristobal Mountains and New Mexico Department of Game and Fish's Red Rock Captive Breeding Facility. Three females died prior to parturition; however, one of these females had prematurely expelled her VIT. Of the 17 females that survived to parturition, all produced viable lambs and 94% ($n = 16$) expelled their VITs ≤1 day of parturition. We captured lambs from 71% ($n = 12$) of the 17 surviving females with VITs, and observed no capture-related abandonment.

South Dakota: East-central Black Hills.—We documented 96 (28 in 2010, 33 in 2011, and 35 in 2012) lambing events of collared females from May 2010 to June 2012 (Table 1). From February 2010 to March 2012, we deployed 62 VITs in collared females (Table 1). However, 2 females with VITs died shortly after capture for reasons apparently not associated with the transmitter or capture in 2011, and 1 additional female with a VIT was not monitored because of logistical error in 2012; thus, all 3 females were censored from further VIT analyses. Number of females fitted with VITs as a percentage of total lambing events observed ranged from 82% ($n = 23$) in 2010 to 49% ($n = 17$) in 2012 (average = 62%, $n = 51$). Number of females retaining VITs to ≤1 day of parturition was 43 (73%, SD = 1.9%, range = 71%, [$n = 12$] to 74% [$n = 17$]; Table 1). When VITs were expelled prior to parturition, they were most often lost approximately 8 weeks post-insertion (range = 5–16 weeks, SD = 3 weeks).

Percentage of lambs captured (or where known fate was obtained; e.g., stillborns or lambs that died prior to collaring) from all radiocollared females, regardless of VIT status, ranged from 86% (24 of 28) in 2010 to 82% (27 of 33) in 2011 (Table 2). We captured slightly more lambs from females that retained VITs to ≤1 day to parturition (41 of 43; 95%) than those that were collared but not fitted with VITs (26 of 37; 70%) or from females that expelled VITs ≥1 day to parturition (13 of 16; 81%). We also observed 2 instances of lamb abandonment likely as a result of capture-related activities.

New Mexico: Fra Cristobal Mountains.—In November 1999, 16 adult females were captured and fitted with VHF collars (MOD-500, Telonics, Inc.) in the Fra Cristobal Mountains. Because of 2 subsequent mortalities, we had 14 radiocollared females in this herd in 2001, which we monitored for hand-capture without the use of VITs. We successfully captured one lamb by hand after monitoring a radiocollared female in 2000 to test the efficacy of this technique. We documented 24 lambing events (15 of collared females and 9 of uncollared females) from January to May 2001. We captured lambs from 27% ($n = 4$) of collared females and 22% ($n = 2$) of uncollared females, for 6 total neonate captures from January to March 2001.

Helicopter Capture

Colorado: Pikes Peak.—We attempted to capture bighorn sheep lambs from the Pikes Peak herd in June 2011, but were unsuccessful. Although we had multiple capture opportunities, our efforts in each case were thwarted by interference of golden eagles (*Aquila chrysaetos*). As we approached with the helicopter and hazed the bighorn sheep groups into an area suitable for capture, eagles that were perched on nearby rocks would fly from their perch and attack the lambs. In 2 instances, eagles successfully caught and killed lambs that we were pursuing. After locating all known groups of bighorn sheep in the area and noting eagle presence at all sites, we abandoned our capture efforts so as to not enable further predation by eagles.

Table 1. Number of confirmed radiocollared bighorn females lambing, status of marked females, and vaginal implant transplant (VIT) functionality in the Black Hills, South Dakota, USA, 2010–2012.

		Females lambing by category		
Year	Total females lambing	Collared only females	Successful VITs	Failed VITs
2010	28	5 (18%)	17 (61%)	6 (21%)
2011	33	14 (42%)	14 (42%)	5 (15%)
2012[a]	35	18 (51%)	12 (34%)	5 (14%)
Total (%)	96	37 (39%)	43 (45%)	16 (17%)

[a] One female with a VIT was censored from 2012 because of logistical error.

Table 2. Total and female category of all captured bighorn lambs in the Black Hills, South Dakota, 2010–2012. VIT = vaginal implant transmitter.

Year	Total lambs captured[b]	Lambs captured by female category[a]		
		Collared only	Successful VITs	Unsuccessful VITs
2010	24 (86%)	3 (60%)	16 (94%)	5 (83%)
2011	27 (82%)	9 (64%)	14 (100%)	4 (80%)
2012[c]	29 (83%)	14 (78%)	11 (92%)	4 (80%)
Sum (%)	80 (83%)	26 (70%)	41 (95%)	13 (81%)

[a] Percentages obtained from lambing marked females for each category by year.
[b] Percentage obtained from lambing marked females by year.
[c] One female with a VIT and lamb was censored from 2012 because of logistical error.

New Mexico: Fra Cristobal Mountains.—We successfully captured bighorn sheep lambs from helicopters in the Fra Cristobal herd in 2001 and 2002. Lambing data for 2001 were presented above. One additional female mortality occurred in 2001. We observed 23 lambs (13 of collared females and 10 of uncollared females) from December 2001 to May 2002.

Helicopter capture operations were conducted on 16 March 2001 and 28 February 2002. On these dates, 11 and 15 lambs (9 of collared females, 2 of uncollared; 12 of collared, 3 of uncollared), respectively, were available for capture. Using the net-gun technique, we captured 36% ($n = 4$) of available lambs in 2001 (2 of collared females, 2 of uncollared) and 47% ($n = 7$) of available lambs in 2002 (5 of collared, 2 of uncollared females), for 11 total successful net-gun captures over 2 years. Additionally, in 2001 we captured 36% ($n = 4$) of available lambs (all lambs of radiocollared females) using the helicopter hand-capture technique. We captured every lamb possible before they moved to inaccessible areas.

In total, we captured 14 lambs in 2001, 8 using the helicopter techniques and 6 using intensive observation of radiocollared females in combination with ground-based capture of neonates. This represented the capture of 71% of lambs of radiocollared females, and 61% of total lambs detected during 2001. We captured 7 lambs in 2002, which represents 39% of lambs born to radiocollared females and 30% of total lambs detected during 2002. Over 3 years, 22 lambs were captured in the Fra Cristobal population, and no capture-related mortalities or lamb abandonment was observed.

South Dakota: Custer State Park.—In July 1999, 3 lambs were collared out of 24 known lambs (13%) in the East End sub-herd, and 7 were collared out of 34 known lambs (21%) in the West End sub-herd. Differences in lambs captured in each sub-herd resulted from varying numbers of lambs found in accessible terrain. In July 2000, 6 lambs were collared in the East End sub-herd of 11 available lambs (55%) and 6 were collared in the West End sub-herd of 38 available lambs (16%). Thus, we captured 22 lambs of 107 known lambs (21%) over the 2 years, and captured every lamb possible before they moved into inaccessible terrain. There were no capture-related lamb mortalities in either year, although there was a single adult female mortality. This mortality occurred when the female was struck by one of the weights attached to the net while confronting the helicopter that was pursuing her lamb. No lamb abandonment was observed using this capture technique.

Cost Estimates

We estimated the individual costs of each of the major aspects of each of the lamb-capture techniques (Table 3). Based on the 2-year average cost estimates, the least expensive lamb-capture technique was helicopter net-gunning of lambs, while the most expensive technique was capture of lambs of radiocollared females with VITs when females were captured via helicopter net-gunning (Table 4). We calculated that 1.28 and 1.41 females would need to be

Table 3. Estimated per-unit capture costs (US$) of technicians, equipment, and helicopter expenses for capturing bighorn sheep lambs using 4 different lamb-capture techniques: 1) hand-capture of lambs from radiocollared females fitted with vaginal implant transmitters (VITs), 2) hand-capture of lambs of intensively monitored radiocollared females, 3) helicopter net-gunning, and 4) hand-capture of lambs from helicopters, based on estimated costs in the United States in 2013, unless otherwise noted.

Technique	Female capture					Lamb capture		
	Dart[a]	Drop-net	Helicopter	VITs	Collars	Monitoring[b,c]	Helicopter	Collars
Females with VITs	$180	$125	$700	$225	$225	$140	NA	$225
Females without VITs	$180	$125	$700	NA	$225	$840	NA	$225
Helicopter net-gunning	NA	NA	NA	NA	NA	NA	$700	$225
Helicopter hand-capture[d]	NA	NA	NA	NA	NA	NA	$900	$225

[a] Assumes on average 1.5 darts required to capture each female.
[b] Assumes 7 hours/lamb and $20/hour [based on Bishop et al. (2007)].
[c] Assumes 42 hours/lamb and $20/hour [based on Bishop et al. (2007)].
[d] Assumes higher cost based on increased attempts to capture lamb.

Table 4. Estimated average number of females required, and yearly and average per-lamb costs (US$) for capturing a bighorn sheep lamb each year of a 2-year study using 4 different capture techniques: 1) hand-capture of lambs from radiocollared females fitted with vaginal implant transmitters (VITs), 2) hand-capture of lambs of intensively monitored radiocollared females, 3) helicopter net-gunning, and 4) hand-capture of lambs from helicopters, based on estimated costs in the United States in 2013.

			Cost		
Technique	**Female capture**	**Female numbers**	**Year 1**	**Year 2**	**Average**
Females with VITs	Dart	1.28[a,b]	$1,174	$1,174	$1,174
Females with VITs	Drop-net	1.28[a,b]	$1,103	$1,103	$1,103
Females with VITs	Helicopter	1.28[a,b]	$1,842	$1,842	$1,842
Females without VITs	Dart	1.41[b,c,d]	$1,635	$1,065	$1,350
Females without VITs	Drop-net	1.41[b,c,d]	$1,557	$1,065	$1,311
Females without VITs	Helicopter	1.41[b,c,d]	$2,366	$1,065	$1,716
Helicopter net-gunning	None	0	$925	$925	$925
Helicopter hand-capture	None	0	$1,125	$1,125	$1,125

[a] Assumes 80% of lambs captured from females with VITs.
[b] Assumes 93% annual female survival rate with mortality occurring in winter months.
[c] Assumes 69% of lambs captured from females without VITs.
[d] Assumes no capture of females needed in second year, marked all in first year.

captured annually and during the first year for radiocollared females with and without VITs, respectively, to capture one lamb during both years. This was based on an estimated annual survival rate of 93% with mortality focused during the winter, and a lamb-capture success rate of 80% from females with VITs and 69% from females without VITs (Table 4).

DISCUSSION

We described and evaluated 4 bighorn lamb-capture techniques. We were able to capture lambs using each technique; however, we captured the largest number of lambs using VITs in combination with radiocollared females. Helicopter net-gunning and hand-capture in conjunction with intensive monitoring of radiocollared females (i.e., no VITs) resulted in fewer captures. The fewest lambs were caught using helicopter hand-capture. Despite differences in the number of lambs captured with these techniques, we observed that each had strengths and weaknesses.

Neonatal Capture

Lamb capture using females with VITs.—Strengths of using VITs compared with the other capture techniques include the following: it was easier to document lambing events, leading to greater capture success; it reduces the need for daily visual observations on females for extended periods of time; it minimizes disturbance to females during the critical lambing period; it lowers observation costs because fewer personnel were needed to monitor females for lambing events; it provides more accurate estimates of parturition dates; it increases probability of documenting early age mortalities (e.g., stillborns); lamb captures can occur throughout the lambing season; and it permits identification of parturition sites. Drawbacks to the use of VITs include the following: it requires trained personnel and an ultrasound at capture; there are costs associated with female capture and VIT deployment; it may entail longer handling times during female captures if helicopters need to ferry animals to a processing location for VIT insertion; it requires repeated capture of females for multiple year studies; aerial monitoring of VITs may be required in areas with low road density or limited access (adding additional cost), and lambs must be neonates (<48 hr old) for successful capture. Also, at locations or during periods of increased temperature or low cloud cover, VITs may emit the "undeployed" pulse rate after expulsion, leading to missed births.

Another potential difficulty associated with the use of VITs is expulsion of the VIT prior to parturition. We found that average VIT retention to parturition across the study areas (78%) was similar to studies that have used VITs in mule deer (Bishop et al. 2007, Tatman et al. 2011), but less than a concurrent study on elk (*Cervus canadensis*) in South Dakota (100% retention; B. Simpson, South Dakota State University, personal communication). Additionally, one animal in New Mexico failed to shed its VIT until 5 days post-parturition, and one VIT in South Dakota failed due to mechanical or battery-related problems. Expulsion and failure would necessitate deployment of ≥20% more VITs to ensure that an adequate sample of neonates was obtained in studies solely using VITs to capture lambs.

We experienced several other problems using VITs. The percentage of neonates successfully captured from females with VITs was similar across years in South Dakota (92–100%), but was lower in New Mexico (71%). This discrepancy was likely because the Black Hills contains the highest road density of any western national forest (3.5 km/km^2; USDA Forest Service 1997). Consequently, of the 6 lambs we failed to capture (NM = 4; SD = 2), 2 were missed because females lambed in inaccessible terrain in New Mexico, which limited both our access and ability to monitor the radio signals of the VITs. We were unable to capture lambs for 3 reasons. First in New Mexico, 2 VITs indicated that the unit was not expelled because of increased temperature or low cloud cover. Thus, the capture crew missed the period when lambs lacked the mobility to escape hand-capture; however, methodology changes (i.e., monitoring in the morning and evening) eliminated this problem later in the study. Second, we searched the area where we presumed the lamb was bedded, but simply failed to find it until the next day when it was too old for hand-capture. Finally, we did not hear the VIT on the day the female lambed because she dispersed approximately 17 km overnight to an area not previously thought to be a lambing area. Based on our observations, it is imperative that VITs be monitored ≥1 times/day with ≥1 monitoring period early in the morning to decrease the chance of obtaining false negatives and ensure that lambs lack the mobility to elude hand-capture, particularly during periods of higher temperatures or low cloud cover. It is noteworthy that recent technological developments of VITs have led to the inclusion of a photosensor in addition to the standard temperature sensor, and this advancement has shown promise in reducing the problem of false negatives (Cherry et al. 2013).

Lamb capture using females without VITs.—The main strength of capturing lambs by intensively monitoring radiocollared females without VITs is that it eliminates the need for multiple captures for long-term studies because females can be followed for the life of their collars. This method also allows the capture of lambs throughout the lambing season, and eliminates the need for ultrasounds during capture to facilitate VIT insertion, which requires specialized equipment and increased animal handling time. However, difficulties of using this technique include: 1) it is challenging to determine parturition events; 2) it requires more intensive monitoring compared with females with VITs (i.e., visual observation of female with or without lamb); 3) it can only be used in areas accessible by foot; 4) it requires bighorn sheep to be reasonably approachable; and 5) it is only useful for capturing neonates.

One additional drawback to this methodology is that it has the potential to increase disturbance to females and lambs during critical times when lambs are most vulnerable. For example in South Dakota, we noted 2 potential instances of female abandonment that may have been related to trying to obtain visuals on radiocollared females. The first instance occurred as we attempted to obtain a visual location on a collared-only female while a separate female and lamb (that was collared the day before) were spotted walking down the same trail. When the female spotted the capture crew she ran off, leaving the lamb. We monitored the female and lamb for several hours via telemetry until we suspected that she would not return because she had moved several kilometers from the lamb. We then captured the lamb and it was sent to a captive facility. The second incident was less obvious, but abandonment could have been the result of our actions. After collaring a lamb from a female with a VIT, we began approaching a second female in the same area not associated with a VIT. The female appeared to stay in the same general area as the newly collared lamb while we moved off over the hill toward the second female. However, the following day the female was not with the lamb and by the second day the lamb had died.

Helicopter Capture

Net-gun.—Strengths of the helicopter net-gun technique include the following: the option to capture in remote terrain not accessible by foot, the ability to capture lambs without intensively monitoring collared females and/or females with VITs, ability to capture lambs of uncollared females, fewer animals need to be captured (i.e., no females), potentially more control over sample size of lambs, and the capacity to capture lambs of varying ages (i.e., not just neonates) to administer various age-dependent treatments (e.g., vaccines). The main limitation of using helicopters for lamb capture is the difficulty in capturing lambs if the females move into heavily forested regions or areas inaccessible to helicopters (e.g., areas with strong winds or high elevation), particularly once they become accustomed to helicopter capture methods. This was the greatest drawback of this technique, and was the main factor limiting the number of lambs captured. Additional limitations include the following: the difficulty in locating an adequate number of lambs to meet sample size goals; particularly in regions with low bighorn densities; a greater risk of physical injury (e.g., being struck by a weight attached to the net); short duration for capture during the lambing season (i.e., only lambs alive while the helicopter is present are available for capture); potential disturbance to non-target animals due to helicopter over-flights; lack of cause-specific mortality data for early age mortalities or information on still-born lambs; lack of data on parturition sites; and the potential for predation of lambs during capture as witnessed in Colorado. It is important to note the impacts of predation are likely site-specific. For example, predation was not a concern in South Dakota or New Mexico where eagles were present and where they did not cause lamb mortality outside of capture activities, in contrast to Colorado. Although we were not able to compare eagle populations and their predation rates across our various study sites and capture years, it is possible that predation risk is related to golden eagle densities or to lambing synchronicity (i.e., higher in areas with shorter, more synchronized lambing seasons, and lower in areas with longer, more temporally distributed lambing seasons). Regardless of the underlying process, impacts of eagle predation may potentially be mitigated by capturing earlier in the lambing season prior to the formation of large nursery groups, or later in the year when the lambs are large enough to be less vulnerable to eagles. However, a greater understanding of the risk factors associated with eagle predation, and appropriate strategies to minimize the effects during helicopter capture operations remain areas for further investigation.

Hand-capture.—In addition to factors previously mentioned in association with the helicopter net-gun technique, the strengths of the helicopter hand-capture technique include the following: decreased risk of physical injury to lambs inherent in net-gunning (e.g., being struck by a weight, being captured in a net with an adult animal); and decreased risk to personnel from nets becoming entangled in helicopter rotors. The limitations of using helicopters for hand capturing lambs include the following: many helicopter models may lack the maneuverability necessary to accommodate personnel exiting the helicopter while hovering; terrain in some areas may preclude hand-capture attempts; this technique requires suitable terrain to "trap" the lamb while the handlers approach and attempt capture; multiple handlers are required for each lamb; it is generally more difficult than helicopter net-gunning; and pilots and handlers may lack experience to conduct this method safely.

Finally, a drawback shared by these helicopter capture techniques is the potential to increase disturbance to females and lambs during critical times when lambs are vulnerable. Bighorn sheep are susceptible to disturbance from helicopters, which may decrease foraging efficiency, increase flight distance, and elevate stress levels in target and non-target animals (Krausman et al. 1985, Miller and Smith 1985, Bleich et al. 1990, Stockwell et al. 1991, Jessup 1992). Thus, these potential effects of helicopter capture of wildlife should be critically evaluated and minimized, if possible, by wildlife professionals when employing these techniques.

Lamb survival and abandonment.—The only potential abandonment issues we observed were associated with hand-capture of neonatal lambs of intensively monitored radio-collared females, as previously described. We did not observe any lamb mortality or abandonment using any of the 3 remaining lamb-capture techniques. When using females fitted with VITs, we observed that one lamb was killed by a gray fox (*Urocyon cinereoargenteus*) 2 days after capture, and one lamb was killed by a golden eagle 4 days after capture; however, capture was not believed to have been a contributing factor. This was particularly evident in the first case where the dam was observed next to the killed lamb's carcass, and she returned to it after the researcher left the site. It also is worth noting that over the course of this study, the vast majority of females stayed relatively close to lambs that were collared, often remaining in sight. Although we did not record exact locations of females immediately following lamb capture, we did monitor their whereabouts and observed several fairly large movements. With the exception of the 2 incidents previously described, females returned to retrieve lambs soon after we left the area.

Cost Estimates

We provided approximate cost estimates because actual cost estimates are largely site and/or herd-specific. This variability arises from, among other things, the feasibility and level of effort required for various female capture techniques, the location and terrain inhabited by the targeted herd, and approachability of animals within the herd. Therefore, we provide only general estimates to help managers identify and approximate potential costs to evaluate each lamb-capture technique. An important aspect to consider in addition to cost is the feasibility of achieving the desired sample size for each lamb-capture technique. We were not able to compare the feasibility of reaching sample-size goals in our study because of the varying effort used with each lamb-capture method. However, we believe that if only one lamb-capture technique is used, hand-capture of lambs from females with VITs is most likely to achieve larger sample sizes, while hand-capture of lambs using helicopters is the least likely.

MANAGEMENT IMPLICATIONS

It is likely that managers may need to plan for and implement the use of multiple techniques to successfully achieve their objectives and reach desired sample sizes. Although bighorn sheep managers need to carefully evaluate the costs, impacts, benefits, and limitations of each of these various methods when choosing which lamb-capture technique to employ, the ability to capture and radiocollar lambs removes many of the impediments to understanding factors influencing lamb recruitment. Specifically, the lamb-capture methods we describe provide a means for managers to investigate questions that were previously difficult or impossible to study in the absence of the ability to capture lambs. For example, managers can examine cause-specific mortality of bighorn sheep lambs; measure the rate of still-born births and abortions; and quantify the efficacy of disease treatments (e.g., vaccines) administered to the dam and/or lamb to improve lamb recruitment.

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