*Management and Conservation Article*

# Evaluating Ungulate Mortality Associated With Helicopter Net-Gun Captures in the Northern Great Plains

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**ABSTRACT** Ungulate mortality from capture-related injuries is a recurring concern for researchers and game managers throughout North America and elsewhere. We evaluated effects of 7 variables to determine whether ungulate mortality could be reduced by modifying capture and handling procedures during helicopter net-gunning. During winter 2001–2006, we captured 208 white-tailed deer (*Odocoileus virginianus*) and 281 pronghorn (*Antilocapra americana*) by helicopter net-gunning throughout the Northern Great Plains. Of 281 pronghorn, 25 (8.9%) died from capture-related injuries; 12 were from direct injuries during capture, and 13 occurred postrelease. Of 208 deer, 3 (1.4%) died from injuries sustained during helicopter captures, with no mortalities documented postrelease. We used logistic regression to evaluate the probability that ungulates would die of injuries associated with helicopter net-gun captures by analyzing effects of snow depth, transport distance, ambient and rectal temperatures, pursuit and handling times, and whether individuals were transported to processing sites. The probability of capture-related mortality postrelease decreased 58% when transport distance was reduced from 14.5 km to 0 km and by 69% when pursuit time decreased from 9 minutes to <1 minute. Wildlife managers and researchers using helicopter capture services in landscapes of the Midwest should limit pursuit time and eliminate animal transport during pronghorn and white-tailed deer capture operations to minimize mortality rates postrelease. (JOURNAL OF WILDLIFE MANAGEMENT 73(8):1282–1291; 2009)

DOI: 10.2193/2009-039

**KEY WORDS** *Antilocapra americana*, capture myopathy, mortality, net-gun, Northern Great Plains, *Odocoileus virginianus*, pronghorn, ungulate, white-tailed deer.

Wildlife research often includes capturing and handling individual animals. Because wildlife can be difficult to monitor, animal capture for marking with radiotransmitters is essential to determine home range use and seasonal movements, survival, cause-specific mortality, habitat use, and disease prevalence (Kernohan et al. 2002, DePerno et al. 2003, Jacques et al. 2007, Oyer et al. 2007, Hurst and Porter 2008). Modern advances in capture techniques and handling methods have minimized the risk of mortality and stress imposed on individual animals at the time of capture (Kock et al. 1987*b*, Beringer et al. 1996, Haulton et al. 2001). These advances have become increasingly important because of the expense and logistics of animal capture and increased public awareness and sensitivity to animal welfare issues (Kock et al. 1987*b*).

Peterson et al. (2003) summarized 16 articles on capture methods used for white-tailed deer (*Odocoileus virginianus*) and showed that mortality rates using net guns (0–2%) was relatively low compared with mortality rates using other capture methods (drive net = 0–7%, box trap = 0–8%, clover trap = 1–21%, rocket-cannon net = 5–24%, dart gun = 0–20%, drop net = 0–7%, corral trap = 14%). In addition to safety, net guns fired from helicopters have become an increasingly popular method of capture because this technique is effective in different terrains, habitat types, and population densities (Webb et al. 2008). Further, helicopter net-guns provide a cost-effective and time-efficient method of selective capture and subsequent deployment of radiocollars (Brinkman 2003, Webb et al. 2008). Other advantages of this technique include short capture and handling times and low risk of mortality associated with stress and capture myopathy (Firchow et al. 1986, Kock et al. 1987*b*). Krausman et al. (1985) noted the importance of selectivity potential with respect to sex and age classes using net-gun capture techniques, and Amstrup and Segerstrom (1981) noted that net-gunning can be conducted without chemical immobilization and subsequent negative effects associated with drugs.

Helicopter net-guns have been used successfully to capture many ungulate species, including white-tailed deer and pronghorn (*Antilocapra americana*). Helicopter net-gun captures of white-tailed deer have safely and successfully occurred in shrubland, agricultural, and forested habitats (Barrett et al. 1982, DeYoung 1988, DelGiudice et al. 2001, Brinkman et al. 2005, Swanson et al. 2008). Webb et al. (2008) evaluated 3,350 helicopter captures of white-tailed deer in Texas, USA, and calculated a direct mortality rate of 0.6% from capture and a postcapture mortality rate of 1.0%. However, there is conflicting evidence about whether this technique is a safe and efficient method for capturing

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pronghorn. Firchow et al. (1986) concluded that net-gunning was an efficient method for capturing pronghorn, whereas Barrett et al. (1982) reported high (20%) mortality rates and cautioned that net-gunning may not be suitable for capture of species susceptible to capture myopathy.

To our knowledge, quantitative estimates of the magnitude of factors affecting capture-related mortality have not previously been documented in ungulate populations in the Northern Great Plains, USA. Because of the unique topography and climate of the Northern Great Plains, susceptibility to mortality from helicopter capture may be unique relative to other regions (i.e., desert scrub and mountain associations, shrubland and forested habitats) where such information has been reported (Barrett et al. 1982, Krausman et al. 1985, Kock et al. 1987*b*, DelGiudice et al. 1989, Webb et al. 2008). Compared with other regions, the Northern Great Plains contains less escape cover, which may lead to prolonged or high-speed captures and, subsequently, greater capture-related mortality rates. Further, dramatic spatial and temporal variation in winter weather (i.e., snow conditions) is typical throughout the Northern Great Plains, with notable differences in snow conditions between Minnesota, USA (substantial snow accumulation) and the Dakotas, USA (minimal snow accumulation). Our objectives were to estimate capture-related ungulate mortality (direct and postrelease) rates associated with helicopter net-gun captures and to quantify the magnitude of animal handling or environmental effects on capture-related ungulate mortality postrelease in the Northern Great Plains.

## STUDY AREA

Our study was conducted in North Dakota, South Dakota, and Minnesota, USA (Fig. 1). The Dakota portion of our study was conducted in north-central and western South Dakota and in western North Dakota. Fall River and Harding counties comprised 12,011 km$^2$ in western South Dakota. Wind Cave National Park (WCNP, Custer County) encompassed 115 km$^2$ and was enclosed by a 2.5-m woven-wire fence, with cattle guards present at all road entrances to prevent movement by ungulates out of WCNP. The study area in north-central South Dakota was conducted in Brown, Edmunds, Faulk, and McPherson counties and comprised an area of 13,094 km$^2$ (South Dakota Agriculture Statistics Service 2006). Billings, Bowman, Golden Valley, and Slope counties comprised 11,830 km$^2$ in western North Dakota and 35 counties comprised the 57,273-km$^2$ study area in southern Minnesota (Fig. 1).

The North Dakota and western South Dakota study areas (Fig. 1) were characterized by a mosaic of mixed-grass prairie interspersed with shrubs (big sagebrush [*Artemisia tridentata*], silver sagebrush [*Artemisia cana*], western snowberry [*Symphoricarpos occidentalis*], wild rose [*Rosa* spp.], common juniper [*Juniperus communis*]) and patches of predominantly ponderosa pine (*Pinus ponderosa*) forest. Topography varied from rolling prairie with occasional buttes and intermittent streams in western South Dakota (Johnson 1976, Kalvels 1982, Johnson 1988), to pinnacles, canyons, domes, gorges, ravines, and gullies associated with the North Dakota badlands (Opdahl et al. 1975, Thompson 1978, Aziz 1989, Smith 2003). Average winter temperature and seasonal snowfall in North and South Dakota was −7.9° C and 71 cm and −5° C and 104 cm, respectively (Opdahl et al. 1975, Thompson 1978, Kalvels 1982, Johnson 1988, Aziz 1989).

North-central South Dakota was characterized by previously glaciated, rolling prairie interspersed with abundant pothole wetland complexes, cultivated agricultural land, intermittent streams, and river floodplains (Bryce et al. 1998). The region was dominated by row crop agricultural activities (Smith et al. 2002). Winter temperature and seasonal snowfall in the region averaged −9.4° C and 85.5 cm, respectively (High Plains Regional Climate Center 2005).

Southwest Minnesota was characterized by flat to rolling topography (Albert 1995). The 34,627-km$^2$ study area comprised 20 counties (Brinkman et al. 2005, Swanson et al. 2008), of which, we selected 3 counties (Lincoln, Redwood, and Renville) for deer net-gun captures. Deer habitat in the region was fragmented and dominated by intense row-crop agriculture. Winter temperature and seasonal snowfall in the region averaged −9.8° C and 105 cm, respectively (Midwest Regional Climate Center 2002).

Southeast Minnesota was characterized by flat to rolling uplands with deep, stream-cut valleys and wooded hillsides (Porter 1976, Minnesota Department of Natural Resources 1979). The 23,096-km$^2$ study area comprised 15 counties, and deer capture sites included portions of 4 counties (Fillmore, Houston, Olmsted, and Wabasha). Deciduous forests dominated valleys and hillsides (Porter 1976, Minnesota Department of Natural Resources 1979). Winter temperature and seasonal snowfall in the region averaged −9.9° C and 106 cm, respectively (Midwest Regional Climate Center 2002). Selected study sites maximized habitat variation throughout the Midwest landscapes.

## METHODS

We captured adult (≥18 months at capture) and yearling (6–18 months at capture) pronghorn by helicopter net-gun (Helicopter Capture Service, Marysvale, UT; Hawkins and Powers, Greybull, WY) throughout western South Dakota during January and February 2002–2003 and throughout western North Dakota during February 2004–2006. During winter 2001–2006, we captured adult (≥18 months at capture) and yearling (6–18 months at capture), female white-tailed deer by helicopter net-gun (Helicopter Capture Service; Quicksilver Air, Fairbanks, AK) at winter deer concentrations throughout southern Minnesota and north-central South Dakota (Fig. 1).

In South Dakota and Minnesota, we physically restrained, hobbled, blindfolded, and aerially transported 81 captured pronghorn and 208 white-tailed deer to predetermined processing sites during all winter capture events. During the April pronghorn capture event in South Dakota, we processed individuals ($n$ = 15) at capture locations to minimize physical injury to developing fetuses and to minimize stress to captured females during less favorable

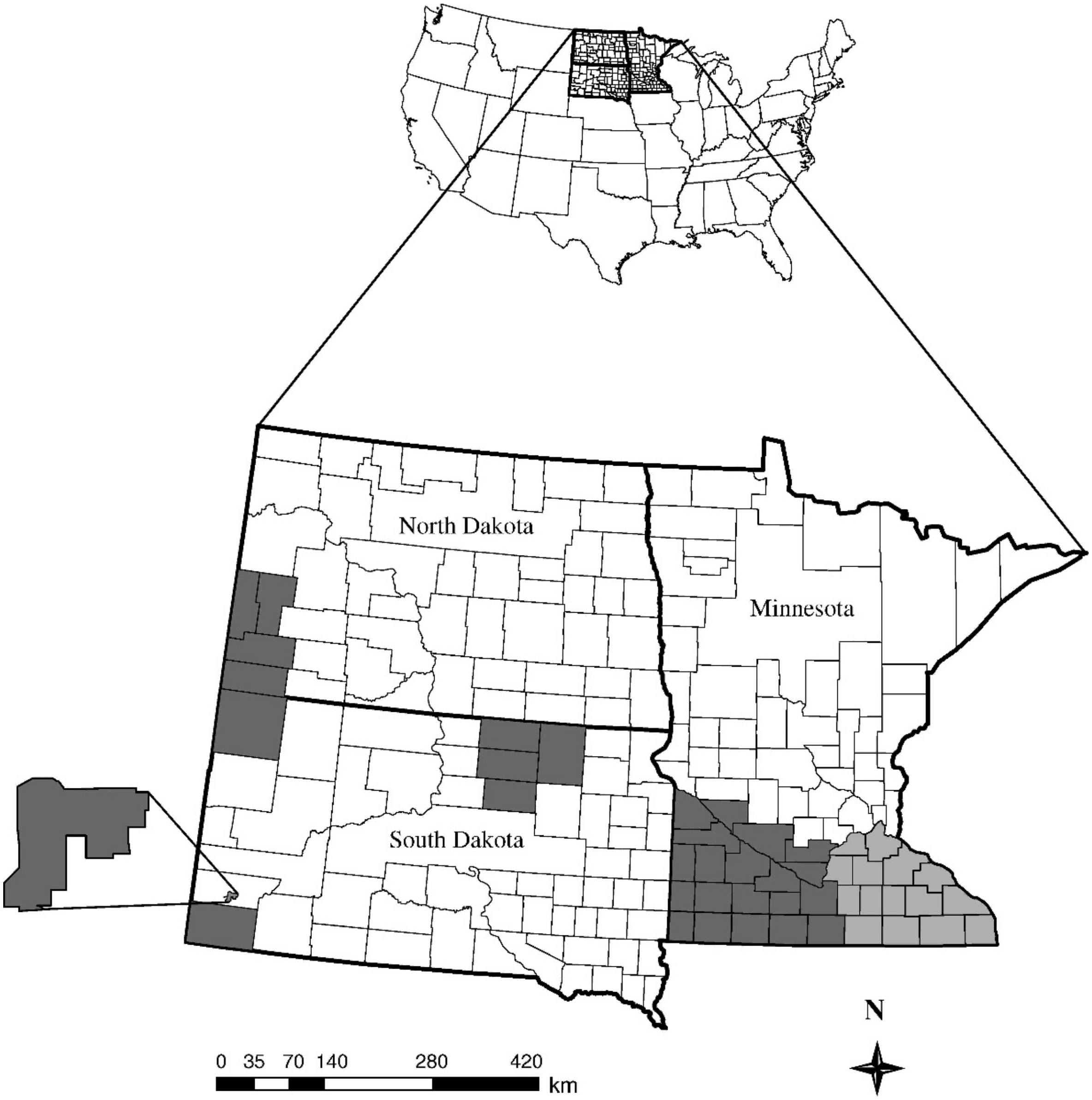

**Figure 1.** Pronghorn and white-tailed deer sites of helicopter net-gun capture throughout the Northern Great Plains, 2001–2006. Pronghorn captures occurred in Harding (northwestern) and Fall River (southwestern) counties and Wind Cave National Park (inset), South Dakota, USA. We captured pronghorn throughout a 4-county area in southwestern North Dakota, USA. We captured white-tailed deer in north-central South Dakota and throughout southwest and southeast Minnesota, USA. Thick black lines delineate state boundaries and thin black lines delineate county boundaries. Study areas in North Dakota, South Dakota, and southwestern Minnesota are shaded dark gray, and the study area in southeastern Minnesota is shaded light gray.

(i.e., warmer ambient temperatures) capture conditions. Because of differing study objectives in North Dakota, we processed all pronghorn ($n = 185$) at capture locations. Animal transport procedures differed between species. For instance, we immediately (although exact times are unknown) transported all white-tailed deer short distances ($<2$ km), whereas we transported most (70 of 96; 73%) pronghorn in groups of 2–3 and often long distances ($\leq 14.5$ km) to processing sites. We did not record data on animal handling time between initial capture and subsequent arrival of pronghorn at processing sites. Thus, length of time captured individuals were immobile until capture of subsequent individuals and group transport is unknown. Because of the small size and confinement of the WCNP pronghorn population, it is possible that individuals may have been pursued multiple times, thus exposing them to higher risk of postrelease mortality than may have occurred in free-ranging populations where multiple groups could be pursued. Thus, we instructed helicopter capture crews to minimize pursuit of previously radiocollared animals. Because of legal issues, we were unable to accompany crew members during capture operations and, thus, do not know if they treated previously captured animals differently. However, we assumed capture crews honored our requests and avoided pursuit of radiocollared animals. Consequently, we did not treat these animals differently in our analyses.

We fitted all animals with mortality sensing, very high frequency radiocollars (Telonics, Mesa, AZ; Advanced

Telemetry Systems, Isanti, MN) and estimated age at capture based on tooth wear and replacement (Severinghaus 1949, Dow and Wright 1962). Additionally, we monitored rectal temperature, collected morphometric measurements, administered a broad-spectrum antibiotic, and ear-tagged all individuals before release. We recorded total handling time and distance from capture locations to processing sites for all individuals. We euthanized animals injured during capture operations with potassium chloride or by head shot. To minimize stress and capture-related mortality on ungulates, we did not record body weight during capture events; thus, we did not include body weight as a covariate in our predictive models. The Institutional Animal Care and Use Committee at South Dakota State University (SDSU; approvals 02-A001, 02-A002, 99-A038, 02-A043, 04-A009) approved all animal-handling methods for deer and pronghorn in South Dakota and Minnesota. Animal handling methods in all study areas, including North Dakota, followed guidelines for the care and use of animals approved by the American Society of Mammalogists (Gannon et al. 2007).

We monitored radiocollared animals for mortality 2–3 times per week from January 2000 to December 2006 using a vehicle-mounted, null-peak antenna system (Brinkman et al. 2002), handheld directional antennas (Telonics), and fixed-wing Cessna 182 (Cessna Aircraft Company, Sacramento, CA) aircraft. We determined cause of death from field necropsy and ancillary evidence at mortality sites. If cause of death was unknown, we transported carcasses to the SDSU Animal Disease Research Diagnostic Laboratory for further investigation. In North Dakota, we determined cause of all capture-related deaths; thus, further investigation of potential causes of death was unnecessary. We verified age of each animal captured in our Minnesota and South Dakota study areas by collecting incisors postmortem and, subsequently, counting cementum annuli (Gilbert 1966). We considered mortalities within 26 days postrelease as related to capture (Beringer et al. 1996), regardless of the ultimate cause of death (e.g., vehicle collision); we considered individuals that survived >26 days survivors. Before analyses, we posited 10 models of how ungulate capture-related mortality postrelease might be influenced by helicopter capture and handling protocols, age, or environmental conditions (e.g., ambient temperature, snow depth) in the Northern Great Plains; we evaluated competing models using information-theoretic methods (Burnham and Anderson 1998). We used Akaike's Information Criterion (AIC) to select a suite of models that best described the data rather than an iterative multiple regression approach that selects only the best model. We compared AIC values to select the most parsimonious model and considered models differing by $\leq 2$ AIC units from the selected model as potential alternatives (Burnham and Anderson 1998). We used Akaike weights ($w_i$) as an indication of support for each model and used a multimodel inference approach to average parameter estimates across competing models (Akaike weights $\leq 0.90$). Within mortality models, we tested predictor variables for collinearity at a qualitative level using Pearson's correlation coefficients ($r > 0.5$). We used principal component analysis with varimax factor rotations (Kaiser 1958) to identify clusters of correlated variables. We used only one variable from a set of collinear variables for modeling and determined predictive capabilities of models with receiver operating characteristic (ROC) values. We considered ROC values between 0.7 and 0.8 an acceptable discrimination and values between 0.8 and 1 excellent discrimination (Hosmer and Lemeshow 2000).

We used Pearson's chi-square analyses using SYSTAT (Systat Software, Chicago, IL; Wilkinson 1990) to test for differences in capture mortality rates among capture companies, species, and age. We set $\alpha$ at $\leq 0.05$ and used Bonferonni correction factors to maintain experiment-wide error rates when performing multiple chi-square analyses (Neu et al. 1974).

## RESULTS

During winter 2001–2006, we captured 208 white-tailed deer and 281 pronghorn by helicopter net-gunning throughout all sites in the Northern Great Plains. Of 281 pronghorn, 25 (8.9%) died from capture-related injuries; 12 individuals died from direct injuries sustained during capture, whereas 13 deaths occurred postrelease. Additionally, 3 of 208 (1.4%) white-tailed deer died from direct injuries sustained during helicopter captures (Table 1); postrelease mortality did not occur for any captured deer.

During winter 2002 and 2003, we captured and radiocollared 96 female pronghorn (74 ad, 22 yearlings; Table 1) at 3 study sites (Fig. 1) in western South Dakota. Of 96 female pronghorn captured, 15 (15.6%) died during helicopter captures; 3 individuals (3.1%) died from direct injuries (i.e., neck, pelvis, and leg fractures) sustained during captures and 12 pronghorn (12.5%) died postrelease from capture. We transported 81 pronghorn to predetermined sites for processing; we did not transport the remaining 15 animals and, subsequently, processed them at capture locations (Table 1). Proximate causes of mortality for capture-related mortalities postrelease included capture myopathy ($n = 10$), coyote (*Canis latrans*) predation ($n = 2$), and entanglement in a barbed-wire fence ($n = 1$). During winter 2004–2006, we captured and radiocollared 185 pronghorn (175 ad, 10 yearlings) throughout southwestern North Dakota, of which, 10 individuals (5.4%) died during helicopter captures; 9 animals (48.6%) died of direct injuries sustained during captures and one death postrelease (i.e., capture myopathy) occurred (Table 1).

We captured and radiocollared 167 female deer (133 ad, 34 yearlings) throughout southern Minnesota during winters 2000–2002 and 41 deer (29 ad, 12 yearlings) in north-central South Dakota during winter 2005 and 2006. Two of 167 (1.2%) and 1 of 41 (2.4%) deer in Minnesota and north-central South Dakota, respectively, died from direct injuries (i.e., fractured legs and pelvis) sustained during helicopter captures; mortality postrelease did not occur for any captured white-tailed deer (Table 1).

We did not conduct field necropsies on all individuals because direct injuries sustained during captures were known; direct injuries (fractured legs, pelvis, vertebra) clearly implicated the role of net gunning in the ultimate cause of death. Capture myopathy-related deaths accounted for 9 (75%) of

**Table 1.** Mortality data for pronghorn and white-tailed (WT) deer during helicopter net-gun capture operations throughout the Northern Great Plains, USA, 2001–2006.

| | | | Transported[b] | | | | Not transported[f] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Study area[a]** | **Winter** | **Species** | **No. animals captured** | **% DM[c]** | **% PRM[d]** | **% total mort.[e]** | **No. animals captured** | **% DM** | **% PRM** | **% total mort.** |
| HC | 2001–2002 | Pronghorn | 30 | 3.3 | 13.3 | 16.7 | 15 | 0 | 0 | 0 |
| WCNP | 2001–2002 | Pronghorn | 11 | 9.1 | 18.1 | 27.2 | 0 | 0 | 0 | 0 |
| FRC | 2002–2003 | Pronghorn | 40 | 2.5 | 15.0 | 17.5 | 0 | 0 | 0 | 0 |
| ND | 2003–2004 | Pronghorn | 0 | 0 | 0 | 0 | 62 | 3.3 | 0 | 3.3 |
| | 2004–2005 | Pronghorn | 0 | 0 | 0 | 0 | 55 | 5.5 | 0 | 5.5 |
| | 2005–2006 | Pronghorn | 0 | 0 | 0 | 0 | 68 | 5.9 | 1.5 | 7.4 |
| MN | 2000–2001 | WT deer | 58 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2001–2002 | WT deer | 73 | 1.4 | 0 | 1.4 | 0 | 0 | 0 | 0 |
| | 2002–2003 | WT deer | 36 | 2.8 | 0 | 2.8 | 0 | 0 | 0 | 0 |
| NCSD | 2004–2005 | WT deer | 41 | 2.4 | 0 | 2.4 | 0 | 0 | 0 | 0 |

[a] HC = Harding County, WCNP = Wind Cave National Park, FRC = Fall River County, NCSD = north-central SD.

[b] Includes individuals that were hobbled and transported to processing sites.

[c] % DM = Percentage of direct mortalities (i.e., head, neck, leg injuries) sustained during helicopter capture operations.

[d] % PRM = Percentage of postrelease mortalities; postrelease mortalities were defined as deaths that occurred within 26 days postrelease.

[e] % Total mort. = Percentage of direct mortalities + percentage of postrelease mortalities.

[f] Includes individuals that were processed at capture sites.

the 12 postrelease mortalities in pronghorn. It was most common to find animals dead without premonitory signs $\leq 7$ days postrelease; however, 3 of the 9 individuals were found in lateral recumbency $\leq 2$ days postrelease and unresponsive to human approach. Clinical signs of all affected animals included gross muscular lesions, associated with widespread and extensive subcutaneous and intramuscular hemorrhage, and fragmentation of muscle fibers (Chalmers and Barrett 1977). We did not observe clinical signs and lesions typical of capture myopathy on the animal that died following entanglement in a barbed wire fence. Nutritional indices (body condition, bone marrow, and kidney fat) indicated that individual was in optimal physical condition.

We conducted all capture operations between $-21°$ C and $13°$ C, and we made 95% of captures when ambient temperatures were between $-13°$ C and $13°$ C. Our results yielded no significant effect ($P = 0.46$) of ambient temperature on capture-related mortality postrelease. However, mean maximum rectal temperature was higher ($F_{1,294} = 16.46$, $P < 0.001$) for postrelease dead animals ($\bar{x} = 40.8°$ C, SE = 0.29, $n = 13$) than survivors ($\bar{x} = 39.6°$ C, SE = 0.06, $n = 282$).

Despite no differences ($F_{1,468} = 0.39$, $P = 0.53$) in processing time between postrelease dead animals ($\bar{x} = 6.12$ min, SE = 0.69, $n = 13$) and survivors ($\bar{x} = 5.53$ min, SE = 0.16, $n = 457$), transport distance was greater ($F_{1,469} = 186.28$, $P < 0.001$) in postrelease dead animals ($\bar{x} = 8.05$ km, SE = 1.13, $n = 12$) than survivors ($\bar{x} = 1.34$ km, SE = 0.08, $n = 458$). Similarly, helicopter pursuit time was greater ($F_{1,264} = 51.3$, $P < 0.001$) in postrelease dead animals ($\bar{x} = 5.78$ min, SE = 0.65, $n = 13$) than survivors ($\bar{x} = 2.50$ min, SE = 0.10, $n = 253$).

We documented no difference ($\chi^{2}_{2} = 4.16$, $P = 0.13$) in capture-related (direct and postrelease) mortality rates between helicopter capture companies. Similarly, capture-related mortality rates were similar ($\chi^{2}_{1} = 0.33$, $P = 0.57$) between individuals transported to processing sites and individuals processed at capture locations (i.e., not transported). Moreover, direct and postrelease mortality rates differed ($\chi^{2}_{3} \geq 10.33$, $P \leq 0.002$) among study areas.

Direct and postrelease mortality rates were higher ($\chi^{2}_{1} \geq 5.40$, $P \leq 0.020$) in pronghorn than in white-tailed deer. Also, mean transport distance was greater ($F_{1,294} = 125.28$, $P \leq 0.001$) for pronghorn ($\bar{x} = 4.36$ km, SE = 0.32, $n = 88$) than for white-tailed deer ($\bar{x} = 1.74$ km, SE = 0.07, $n = 208$). Interestingly, pronghorn postrelease mortality rates were higher ($\chi^{2}_{1} = 16.45$, $P \leq 0.001$) in yearlings than adults.

Before model development, analysis of predictor variables revealed linear associations among variables. Rotated factors revealed 2 collinear variables: transport and transport distance. Thus, only one variable (transport distance) from the set of collinear variables was used in model development. The transport distance–pursuit time model was clearly the optimal model ($w_i = 0.999$; Table 2) for predicting ungulate capture-related mortality postrelease. Predictive capability of the model was excellent (ROC = 0.92; Table 2).

Interestingly, probability of postrelease mortality decreased by 58% (odds ratio = 0.419, 95% CI = 0.267–0.658) when transport distances were reduced from 14.5 km to 0 km, and by 69% (odds ratio = 0.308, 95% CI = 0.156–0.611) when helicopter pursuit time decreased from 9 minutes to <1 minute. Parameter and standard error estimates were consistent among models where transport distance ($\beta = -0.870$, SE = 0.230) and pursuit time ($\beta = -1.176$, SE = 0.349) covariates occurred, and 95% confidence intervals never overlapped zero, suggesting these variables influenced postrelease capture mortality. However, 95% confidence intervals for parameter estimates of ambient temperature ($\beta = 0.082$, 95% CI = $-0.112$ to 0.277), rectal temperature ($\beta = -0.120$, 95% CI = $-1.258$ to 1.019), age ($\beta = 0.420$, 95% CI = $-0.040$ to 0.879), snow depth ($\beta = 1.835$, 95% CI = $-0.079$ to 3.749), and processing time ($\beta = -0.010$, 95% CI = $-0.293$ to 0.272) covariates always overlapped zero, and $P$ values based on permutation tests for these covariates were not significant ($P \geq 0.22$), suggesting these factors had little effect on ungulate capture mortality

**Table 2.** Akaike's Information Criterion model selection of a priori logistic regression models for ungulate capture mortality in the Northern Great Plains, USA, 2001–2006.

| Model covariates[a] | $K$[b] | $N$[c] | Log-likelihood | AIC[d] | ΔAIC[e] | $w_i$[f] | ROC[g] |
|---|---|---|---|---|---|---|---|
| TD + PUT | 4 | 266 | −10.327 | 26.653 | 0.000 | 0.999 | 0.923 |
| RT + TD + SD + CC | 6 | 90 | −15.174 | 40.347 | 13.694 | 0.001 | 0.941 |
| AT + RT + TD + PT | 6 | 90 | −17.028 | 44.056 | 17.403 | 0.000 | 0.927 |
| TD | 3 | 266 | −24.546 | 53.091 | 26.438 | 0.000 | 0.902 |
| TD + PT | 4 | 266 | −24.524 | 55.048 | 28.395 | 0.000 | 0.903 |
| PUT | 3 | 266 | −30.897 | 65.793 | 39.140 | 0.000 | 0.871 |
| SD + RT | 4 | 90 | −34.399 | 74.798 | 48.145 | 0.000 | 0.607 |
| T + PT | 4 | 266 | −39.222 | 84.445 | 57.792 | 0.000 | 0.839 |
| AGE | 3 | 266 | −47.403 | 98.807 | 72.154 | 0.000 | 0.669 |
| PT | 3 | 266 | −49.004 | 102.009 | 75.356 | 0.000 | 0.725 |

[a] AT = ambient temp, CC = capture company, PT = processing time, PUT = helicopter pursuit time, RT = rectal temp, SD = snow depth, TD = transported distance, T = transported, AGE = age of ungulate (in yr).

[b] No. of parameters.

[c] Sample size.

[d] Akaike's Information Criterion (Burnham and Anderson 1998).

[e] Difference in AIC relative to the min. AIC.

[f] Akaike wt (Burnham and Anderson 1998).

[g] ROC = area under the receiver operating characteristic curve. Values between 0.7 and 0.8 were considered acceptable discrimination, and values between 0.8 and 1.0 were considered excellent discrimination (Hosmer and Lemeshow 2000).

postrelease. Parameter and standard error estimates were consistent among models where capture company (β = −5.041, 95% CI = −9.400 to −0.683) and transported (β = 0.419, 95% CI = 0.232–0.757) covariates occurred, and 95% confidence intervals never overlapped zero, suggesting these variables may have influenced postrelease capture mortality. However, models that included these covariates were unsupported by our data ($w_i$ = 0.000; Table 2) and, consequently, had little effect on ungulate capture-related mortality postrelease.

Mean transport distance ranged from 0 km to 5.8 km among study areas (Tables 3, 4). Similarly, mean pursuit time, rectal temperature, snow depth, ambient temperature, processing time, and age ranged from 1.7 minutes to 3.1 minutes, 39.4° C to 40.4° C, 0.3 cm to 13.1 cm, −7.2° C to 4.9° C, 1.7 minutes to 8.1 minutes, and 0.5 years to 13.5 years, respectively, among study areas (Tables 3, 4). Pronghorn captured in North Dakota and all white-tailed deer were classified according to age as adult, yearlings, and fawns; thus, mean age was not calculated.

## DISCUSSION

Helicopter net-gunning was an efficient and safe method for capturing white-tailed deer, but problematic for pronghorn. Further, our analyses suggested that differential direct ungulate mortality rates among study areas were influenced, in part, by differences in winter capture conditions. In our North and South Dakota study areas, we conducted capture operations during relatively unfavorable winter conditions (minimal snow cover, variable ambient temp), whereas suitable snow cover and cold ambient temperatures throughout southern Minnesota prevailed. Consequently, differences in ambient temperatures and snow conditions in the North and South Dakota study areas contributed to high capture-related pronghorn mortality rates. In contrast, greater snow depth and colder ambient temperatures throughout southern Minnesota contributed to low capture-related deer mortality rates. Capture-related deaths (direct and postrelease) for white-tailed deer (1.4%) were similar to previously documented mortality rates (0%, White and Bartmann 1994; 2%, DelGiudice et al. 2001; 1.6%,

**Table 3.** Mean, range, and standard error estimates for covariates used in logistic regression models for predicting ungulate capture mortality in Harding and Fall River counties and Wind Cave National Park, South Dakota, USA, 2001–2006.

| | Harding County[b] | | | Fall River County[c] | | | Wind Cave National Park[d] | | |
|---|---|---|---|---|---|---|---|---|---|
| Mod. par.[a] | $\bar{x}$ | SE | Range | $\bar{x}$ | SE | Range | $\bar{x}$ | SE | Range |
| TD | 3.1 | 0.4 | 0–10.2 | 5.8 | 0.5 | 2.4–14.5 | 3.0 | 0.5 | 1.2–5.4 |
| PUT | 1.7 | 0.3 | 0.3–9.0 | 2.4 | 0.3 | 0.3–8.0 | 3.1 | 0.7 | 0.5–7.0 |
| RT | 39.4 | 0.2 | 36.9–41.8 | 40.3 | 0.1 | 38.8–41.4 | 39.6 | 0.9 | 39.4–41.0 |
| SD | 1.7 | 0.2 | 0–2.5 | 0.4 | <0.001 | 0.1–0.5 | 1.3 | <0.001 | 0–3.3 |
| AT | −5.9 | 1.2 | −11.6–5.6 | 1.1 | <0.001 | 1.0–1.2 | −2.4 | <0.001 | −4.6–1.1 |
| PT | 6.5 | 0.4 | 3.0–13.0 | 6.9 | 0.4 | 3.3–10.0 | 8.1 | 0.5 | 6.0–12.0 |
| AGE | 3.8 | 0.3 | 1.5–13.5 | 3.1 | 0.3 | 0.5–9.5 | 4.8 | 0.9 | 1.5–10.5 |

[a] Mod. par. = model parameter, TD = transported distance (in km), PUT = helicopter pursuit time (min), RT = rectal temp (°C), SD = snow depth (cm), AT = ambient temp (°C), PT = pursuit time (min), AGE = age of ungulate (yr).

[b] Harding County parameter estimates were calculated using 45 ad F pronghorn.

[c] Fall River County parameter estimates were calculated using 37 ad F pronghorn.

[d] Wind Cave National Park parameter estimates were calculated using 11 ad F pronghorn.

**Table 4.** Mean, range, and standard error estimates for covariates used in logistic regression models for predicting ungulate capture mortality in southwestern North Dakota, southern Minnesota, and north-central South Dakota, USA, 2001–2006.

| | **ND**[b] | | | **MN**[c] | | | **North-central SD**[d] | | |
|---|---|---|---|---|---|---|---|---|---|
| **Mod. par.**[a] | $\bar{x}$ | **SE** | **Range** | $\bar{x}$ | **SE** | **Range** | $\bar{x}$ | **SE** | **Range** |
| TD | 0 | 0 | 0 | 1.7 | 0.1 | 0.1–9.0 | 2.0 | 0.1 | 0.7–3.9 |
| PUT | 3.0 | 0.1 | 1.0–5.0 | | | | | | |
| RT | | | | 40.4 | 0.1 | 37.2–42.2 | 40.2 | 0.1 | 39.1–41.1 |
| SD | 7.0 | 0.5 | 0–15.2 | 13.1 | 0.7 | 0–31.0 | 0.3 | 0.1 | 0–0.7 |
| AT | −0.1 | 1.2 | −7.9–5.6 | −7.2 | 0.4 | −13.3–3.6 | 4.9 | 1.2 | −2.8–13.3 |
| PT | 3.0 | 0.1 | 1.0–5.5 | 8.5 | 0.2 | 4.0-19.0 | 1.7 | 0.1 | 1.0–2.5 |

[a] Mod. par. = model parameter, TD = transported distance (km), PUT = helicopter pursuit time (min), RT = rectal temp (°C), SD = snow depth (cm), AT = ambient temp (°C), PT = pursuit time (min), AGE = age of ungulate (yr). Blank cells represent no data.

[b] ND parameter estimates were calculated using 185 ad pronghorn.

[c] MN parameter estimates were calculated using 167 F white-tailed deer.

[d] North-central SD parameter estimates were calculated using 41 F white-tailed deer.

Webb et al. 2008). Conversely, capture-related deaths (direct and postrelease) for pronghorn (9%) were moderate to high (3–20%) compared with other ungulate net-gun captures (12%, Barrett et al. 1982; 10%, Krausman et al. 1985, Firchow et al. 1986; 12%, Kock et al. 1987*b*; <3%, Kock et al. 1987*a*).

The rectal temperature trend we observed was consistent with stress-induced hyperthermia dynamics and subsequent return to basal temperature values after capture-related physical activity (DelGiudice et al. 1989, 2001). Whether rectal temperatures at, or shortly after, capture exceeded our recorded temperatures remains unknown. However, it is possible that transporting animals may have reduced rectal temperatures, thereby, minimizing a body temperature effect on capture-related mortality postrelease.

In our study, which included relatively large sample sizes, differences in temperature between postrelease dead animals and survivors were notable. Mean maximum temperature for postrelease dead animals was 40.8° C, compared with 39.3° C in survivors. Despite no differences ($P$ = 0.53) in processing time between postrelease dead animals and survivors, our analyses yielded significantly ($P$ < 0.001) greater transport distances and pursuit times for postrelease dead animals than for survivors. We suggest the additive effects of increased helicopter pursuit time and transport distance contributed to dramatic differences in body temperature and subsequent capture-related mortality rates between postrelease dead animals and survivors. Moreover, we conducted all capture operations in a relatively narrow range of cool ambient temperatures (−13° C to 13° C), which may have limited our ability to detect an ambient temperature effect on ungulate mortality postrelease. However, several studies have suggested associations of high body temperatures with postrelease mortalities of deer (Seal et al. 1978, Kocan et al. 1980, DelGiudice et al. 1989). Unfortunately, reported sample sizes were small or were of insufficient detail regarding capture and handling techniques to provide a holistic understanding of the strength of potential relationships. Nevertheless, Seal et al. (1978) reported that white-tailed deer that died at, or shortly after, capture had rectal temperatures of ≥40° C; no postrelease mortality occurred when body temperature ranged from 37.2° C to 39.9° C at capture. DelGiudice et al. (2001) documented no differences in mean initial, maximum, minimum, and final temperatures of postrelease (clover trapped) dead deer and individuals that survived beyond 2 weeks postcapture. Additionally, they documented one postrelease mortality from capture by helicopter net-gun; these results supported a potential relationship between body temperature and postrelease mortality in net-gunned deer.

Our analyses indicated that differences in transport distances among study sites contributed to differing postrelease mortality rates between species and study areas. For instance, we often transported South Dakota pronghorn long distances (up to 14.5 km) to processing sites, whereas we did not transport North Dakota pronghorn to processing sites and we transported all white-tailed deer <2 km to processing sites. Consequently, postrelease mortality was higher ($P$ = 0.001) in South Dakota pronghorn than in North Dakota pronghorn; postrelease mortality was not documented in any white-tailed deer. Furthermore, our predictive models indicated a strong direct relationship between postrelease mortality and transport distance, and postrelease mortality decreased 58% when transport distance decreased to 0 km. It is possible that transport distance may have been confounded by animal handling time. Unfortunately, we did not record data on animal handling time between the time of initial capture and the subsequent arrival of individuals to processing sites; however, this variation in time was accounted for in the variation explained by the transport-distance model covariate. Firchow et al. (1986) and DelGiudice et al. (2001) also stressed the importance of minimizing transport distances to reduce capture-related mortality postrelease (Firchow et al. 1986, DelGiudice et al. 2001).

Our results indicated that potential for injury and stress associated with capture-related mortality postrelease increased markedly because of circumstances associated with group transport and variation in transport distances. Previous reports of capture-related ungulate mortality postrelease have also suggested an association between translocation and subsequent postrelease mortality. Jones et al. (1997) evaluated the hypothesis that female white-tailed deer translocated with other members of their social group had higher postrelease survival than unrelated deer. Interestingly, they detected no difference ($P$ = 0.47) in postrelease survival among translocated groups of deer; however, translocated deer had lower postrelease survival than resident deer at release sites. Similarly, in their investigation of capture myopathy in pronghorn, Chalmers and Barrett (1977) reported that, of 594 drive-trapped animals, 74 (12.5%) were subsequently transported to enclosures; postrelease deaths attributed to capture myopathy occurred in 20 animals (3.4%); 17 of those 20 (85%) were trapped and subsequently transported. Moreover, they noted that deaths attributed to capture myopathy were "fewer when the transportation distance was short" (Chalmers and Barrett 1977:919), suggesting that capture-related mortality postrelease was directly related to distances that animals were translocated.

Our analyses indicated that reducing helicopter pursuit time, from 9 minutes to <1 minute, decreased postrelease mortality by 68%. Our analyses yielded results consistent with previous studies (Barrett et al. 1982, Firchow et al. 1986) and further highlighted the importance of minimizing helicopter pursuit effects and of using short pursuit times and experienced personnel to haze animals uphill through deep snow to reduce animal speed and subsequent capture-related mortalities.

Interestingly, the highest postrelease mortality rates (18%) documented during our study occurred in WCNP, which was enclosed by a 2.5-m-tall woven-wire fence, with cattle guards at all road entrances to prevent ungulate movement out of the Park. During our study, the estimated WCNP pronghorn population consisted of 31 individuals in 2 social groups (Sievers 2004), which was comparably smaller than other free-ranging populations involved in our study. Further, the size and confinement of the WCNP pronghorn populations indicated the same individuals likely were pursued repeatedly during capture operations. Consequently, cumulative helicopter pursuit times may have predisposed individuals to higher rates of capture-related mortality postrelease than would have occurred in other larger, free-ranging populations where multiple groups could be pursued. The advantages of an experienced crew for capture operations (Webb et al. 2008) coupled with landscapes in the Midwest that are favorable for reducing animal speed relative to other regions may aid in minimizing potential effects of helicopter pursuit times on postrelease mortality rates, especially when population size is small and few groups are available for capture.

Few detailed reports evaluated effects of age on ungulate capture-related mortality rates. Haulton et al. (2001) noted that 42% of white-tailed deer mortalities captured with Stephenson box traps were <1-year-old deer in a population ranging in age from 1 year to 18 years old. Kock et al. (1987*a*) noted differences in biochemical parameters, particularly cortisol levels, among older-aged bighorn sheep (*Ovis canadensis*) males, young males, and females, suggesting a potential age effect on capture-related stress and subsequent mortality. To our knowledge, age effects on ungulate capture-related mortality postrelease as a result of helicopter net-gunning have not previously been documented. During our study, estimated ages ranged from 0.5 years to 13 years old and 15% and 3% of postrelease mortalities were yearling and adult animals, respectively. Interestingly, the age covariate was an insignificant predictor of ungulate capture-related mortality postrelease likely because nearly all (99.9%) of the variation in our data was explained by the optimal predictive model. Although not quantified, we speculate that a combination of physical (smaller bodied), physiological (increased adrenalin response), and socio-behavioral (less experience) factors may have predisposed younger animals to higher rates of capture-related mortality postrelease.

## MANAGEMENT IMPLICATIONS

Helicopter net-gunning was an efficient and safe method for capturing white-tailed deer in the Midwest landscapes. However, relatively high, region-specific, pronghorn postrelease mortality rates ($\leq 18\%$) indicate that prolonged pursuit times and long transport distances to processing sites have serious negative effects on survival. Unless specific study objectives warrant animal transport (e.g., fitting animals with vaginal implant transmitters, tissue collection [tonsillar biopsies] for disease testing), we recommend eliminating animal transport and limiting pursuit times to <5 minutes to minimize subsequent postrelease mortality rates.

Also, we recommend that quantitative data on total animal handling time be collected and incorporated into mortality models to increase understanding of an animal handling effect on rates of capture-related ungulate mortality postrelease. Quantitative information on relative animal speed (stationary, full sprint) and landscape characteristics (flat or hilly terrain, wooded draw, agricultural land, prairie habitat) at capture locations may help to elucidate potential effects of intrinsic and extrinsic factors on ungulate capture-related mortality postrelease.

## ACKNOWLEDGMENTS

Funding was provided by Federal Aid in Wildlife Restoration administered by South Dakota Department of Game, Fish and Parks, study 75103; Minnesota Department of Natural Resources; North Dakota Department of Game and Fish; the National Park Service, administered through the South Dakota Cooperative Fish and Wildlife Research Unit at SDSU; the Pope and Young Club; Safari Club International (Dacotah and North Country Bowhunters chapters); Bluffland Whitetails Association; Cottonwood County Game and Fish League; Minnesota Bowhunters, Inc.; Minnesota Deer Hunters Association (Bend of the River, Des Moines Valley, Rum River, and South Metro chapters); Minnesota State Archery Association; Whitetail Institute of North America; and the Department of Wildlife and Fisheries Sciences at SDSU. We thank G. D. DelGiudice, L. P. Hansen, and K. R. McCaffery for their insightful comments on earlier drafts of our manuscript. We thank P. Bauman, The Nature Conservancy, and numerous volunteers for their assistance capturing and monitoring animals. In addition, we thank D. Carpenter, South Dakota Civil Air Patrol for aerial assistance, and all the landowners who allowed access to their properties during our study.

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*Associate Editor: Hall.*