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*Original Article*

# Body Condition and Dosage Effects on Ketamine–Xylazine Immobilization of Female White-Tailed Deer

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**ABSTRACT** Ketamine and xylazine are an effective chemical combination for white-tailed deer (*Odocoileus virginianus*) immobilization, but the effects of body condition on ketamine–xylazine efficacy have not been examined. We assessed the influence of ketamine dosage, xylazine dosage, body condition, age class, and injection site on successful adult female deer chemical immobilization. From January to March 2009–2011, we captured 87 deer (age $\geq$1.5 yr) in Clover traps and immobilized them using ketamine–xylazine ratios of 400 mg ($n = 58$) or 300 mg ($n = 29$) of ketamine to 100 mg of xylazine. Mean deer body mass was 67.8 kg (SD = 12.3, range = 43.0–93.0). We considered immobilization successful if deer induction was achieved $\leq$15 minutes from first ketamine–xylazine injection. Seventy-five percent of injected deer (81% with 400:100 mg ketamine:xylazine; 62% with 300:100 mg ketamine:xylazine) achieved successful induction. We recorded deer heart rate, respiration rate and rectal temperature at 0 minutes, 10 minutes, and 20 minutes post-induction. Comparison of 7 generalized linear models indicated that the probability of successful induction increased by about 6.7% with every 1.0 mg/kg increase in ketamine dosage and by about 0.7% with every 1-unit decrease in body-condition index. The remaining parameters did not influence the success of deer induction. Deer heart rate, respiration rate, and rectal temperature decreased over time post-induction, with >95% within reported ranges for ketamine–xylazine immobilization. We suggest that deer weighing $\leq$93.0 kg be injected with 5.8 mg/kg ketamine and 1.6 mg/kg xylazine to produce satisfactory induction when using similar capture methods during winter. © 2012 The Wildlife Society.

**KEY WORDS** body condition, capture, deer, immobilization, ketamine, *Odocoileus virginianus*, xylazine.

Chemical immobilization is often necessary in wildlife research and management, and advancing the understanding of chemical efficacy is central to improving animal handling procedures (Beringer et al. 1996; Mitcheltree et al. 1999; DelGiudice et al. 2001, 2005; Kreeger and Arnemo 2007). Common goals of animal field capture and handling are to minimize time to induction and any adverse effects to animals being studied (DelGiudice et al. 2005). Therefore, use of effective immobilization chemicals and dosages is essential to minimize animal injury or death (Conner et al. 1987, Beringer et al. 1996, DelGiudice et al. 2005, Kreeger and Arnemo 2007). Factors to consider when evaluating the safety and efficacy of immobilizing chemicals include low effective volume, short induction time, consistent immobilization time, and existence of an antagonist, or reversal drug (Pond and O'Gara 1996, Massolo et al. 2003). Additionally, practitioners should consider how immobilization could be affected by factors such as variation in capture method (DelGiudice et al. 2001), physiological rates (Mitcheltree et al. 1999; DelGiudice et al. 2001, 2005; Millspaugh et al. 2004), age (Kreeger and Arnemo 2007), chemical injection site (Plotka et al. 1987, Slip and Woods 1996), environmental conditions (DelGiudice et al. 2001, 2005), and animal body condition (Sweitzer et al. 1997).

Animal body condition is important to consider when evaluating chemical immobilization because chemicals are not absorbed at the same rate among body tissues (Slip and Woods 1996). Animals in better condition tend to metabolize chemicals more slowly (Sweitzer et al. 1997) and variation in body fat levels (Cook et al. 2001) and body mass (Stephenson et al. 1998) can influence chemical efficacy. In addition, chemical absorption rates can differ among injection sites, but are typically quicker in the shoulder than in the rump region (Kreeger and Arnemo 2007). In ungulates, body

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regions such as the rump often possess greater amounts of fat (e.g., Cook et al. 2010). Therefore, the choice of chemical injection site (e.g., shoulder or rump) may influence efficacy of induction, because sites with increased fat could result in slow or unpredictable absorption, leading to prolonged induction or failure of effect (Pond and O'Gara 1996). Specifically, white-tailed deer (*Odocoileus virginianus*) exhibit variable body condition during winter (DelGiudice et al. 1990), leading to potential variation in chemical efficacy. Biologists commonly capture white-tailed deer during winter in northern climates when they exhibit reduced fat stores (Mautz 1978). Despite the potential influence of body condition and injection site on chemical immobilization efficacy, these relationships for ungulates have received little attention, particularly for white-tailed deer.

Veterinarians have commonly recommended a combination of ketamine (a cyclohexamine) and xylazine (an analgesic) for immobilization of white-tailed deer (Kreeger and Arnemo 2007); however, biologists have used various ratios and dosages. Injections of a 300:100 mg of ketamine:xylazine at 4.75 mg/kg and 1.58 mg/kg, respectively, successfully immobilized white-tailed deer in the field (Kreeger et al. 1986). Similarly, other ketamine–xylazine dosages provided rapid and smooth induction (e.g., 7.5 mg/kg and 1.5 mg/kg; Kreeger and Arnemo 2007). Although multiple ketamine–xylazine ratios have been successful, comparisons of their efficacy for field immobilization of white-tailed deer are not available. Further, immobilization chemicals are typically expensive and identifying minimum amounts of chemicals that produce effective deer induction would reduce research costs, such as reducing a ketamine:xylazine ratio from 500:100 mg to 400:100 mg. Ideal chemical doses would minimize the amount of chemicals needed while providing enough time to complete handling procedures (Pond and O'Gara 1996, Kreeger and Arnemo 2007). Therefore, following DelGiudice et al. (2001) we assessed the efficacy of administering 300 mg or 400 mg of ketamine with 100 mg of xylazine to achieve chemical induction in white-tailed deer.

We assessed successful immobilization efficacy of female white-tailed deer during winter relative to 1) ketamine and xylazine dosage, 2) body condition, 3) injection site, and 4) age class. We also assessed the physiological response of deer relative to successful and unsuccessful induction over time. We predicted that probability of successful induction would be greater with a 400-mg dose of ketamine than with a 300-mg dose. We also predicted that the probability of successful induction would be greater with a shoulder injection than a rump injection, and would increase with decreasing deer body condition because of reduced chemical absorption time due to less resistance from soft tissue.

## STUDY AREA

We captured deer in the south-central Upper Peninsula of Michigan, USA (45°43′47″N, 87°4′48″W). Mean elevation was 185 m above sea level and topography was flat. Uplands consisted of a mix of coniferous and deciduous forests, and conifer-dominated lowlands, including eastern white cedar (*Thuja occidentalis*) and eastern hemlock (*Tsuga canadensis*). The western portion of the study area was interspersed with pasture and cropland. Mean daily snow depth during the study was 9.6 cm (SE = 0.5). Mean daily maximum and minimum temperatures during the study were 5.6° C (SE = 0.8) and −6.3° C (SE = 0.7), respectively.

## METHODS

We captured 87 female white-tailed deer (age ≥1.5 yr) in baited collapsible Clover traps (Clover 1956) from January to March 2009–2011. We hand-mixed a 300:100 mg or 400:100 mg ketamine–xylazine combination of 100 mg/ml ketamine (Ketaset®; Fort Dodge Laboratories, Inc., Fort Dodge, IA) and 100 mg/ml xylazine (X-Ject E™; Butler Schein Animal Health, Dublin, OH) daily before deer captures. We manually restrained deer by collapsing the traps, and we hand-injected deer intramuscularly in the rump (14 with 300:100 mg and 32 with 400:100 mg ketamine–xylazine) or shoulder (15 with 300:100 mg and 26 with 400:100 mg ketamine–xylazine) using a 3.75-cm needle. Immediately after injection we covered the animal's eyes and recorded time to first noticeable chemical effect (e.g., change in respiration or lessened resistance to manual restraint) and induction time, which we defined as ataxia of limbs and lack of obvious eye reflex to external stimulation (e.g., Miller et al. 2003). We considered immobilization successful if induction was achieved ≤15 minutes from first ketamine–xylazine injection (DelGiudice et al. 2005). At 15-minute intervals post-initial injection, we injected deer that did not induce by using ketamine equal to half the dose of the initial ketamine injection to achieve induction.

After induction, we applied ophthalmic ointment and blindfolded deer before removing them from the trap. We laid deer sternally recumbent on a canvas tarp and occasionally cooled (i.e., snow-packed) or warmed (covered with sleeping bag) deer depending on weather and rectal temperatures. We recorded heart rate (via auscultation), respiration rate (observing thoracic movements), and rectal temperature (ReliOn® digital thermometer; MABIS Healthcare, Waukegan, IL) immediately after induction and at approximately 10-minute intervals up to 20 minutes post-injection. We extracted a lower canine for age estimation (Nelson 2001) and used examination of incisor cementum layers to categorize deer as yearling (1.5-yr-old, $n = 19$), prime-age (2.5- to 6.5-yr-old, $n = 28$), or late-age (7.5- to 15.5-yr-old, $n = 37$; Verme 1969); age was not available for 3 deer. We recorded deer body mass (kg) by elevating deer in a canvas tarp attached to a tared spring scale (Model IC-500®; Chatillon Force Measurement Systems, Largo, FL) and right hind-foot length (cm) measured from the top of the calcaneum to the tip of the hoof using a flexible tape measure. We also developed a deer body-condition index following Toïgo et al. (2006) using the residuals from the linear regression of body mass and right hind-foot length (body mass = −60.82 + 2.85 ln[right hind-foot length], $R^2 = 0.42$, $P < 0.01$, df = 72). We developed this index to provide an objective estimate of body condition (i.e., mass

for a given size) because this could influence variation in chemical immobilization efficacy.

We administered 4.4–15.0 mg of yohimbine (Hospira©; Forest Lake, IL) intravenously or intramuscularly to antagonize effects of xylazine. Several deer required additional yohimbine injections due to extended induction time and temperatures that were approaching critical levels, and therefore yohimbine dosages were variable and were not comparable with induction times. We released all deer at their respective capture sites. All procedures were approved by the Mississippi State University Institutional Animal Care and Use Committee (no. 09-004).

We used Pearson product-moment correlation analyses of model predictor variables. We used generalized linear models with a binomial family to evaluate the relationship of induction success with the following predictors: ketamine dosage and xylazine dosage, body-condition index, age class, and injection site. We log-transformed ketamine dosage and xylazine dosage to improve model fit and did not evaluate any models with both xylazine dosage and ketamine dosage because these parameters were correlated ($r = 0.78$, $P < 0.01$). We considered induction unsuccessful if it occurred after 15 minutes post-injection or if deer required additional ketamine injections equal to half the dose of the initial injection. We used Akaike's Information Criterion corrected for small sample size ($AIC_c$) for model selection and ranked models using $\Delta AIC_c$ and $AIC_c$ weight; competing models were considered when the difference with the best model was $\leq 2$ $\Delta AIC_c$ (Burnham and Anderson 1998). All analyses were performed in Program R 2.12.1 (The R Development Core Team 2010) and we used $\alpha = 0.05$.

## RESULTS

Seventy-five percent of all injected deer, 81% given a ketamine:xylazine dose of 400:100 mg and 62% given a 300:100 mg, achieved induction (Table 1). Remaining deer required 2 ($n = 13$), 3 ($n = 7$), or 4 ($n = 2$) ketamine doses to reach induction. Overall mean ketamine and xylazine dosage was 5.6 mg/kg (SE = 0.1) and 1.5 mg/kg (SE = 0.0), respectively. No model parameters were significantly autocorrelated ($r = -0.24$ to 0.21, $P = 0.20$–$0.96$). Mean deer mass was 67.8 kg (SD = 12.3).

Deer heart and respiration rates and rectal temperatures were generally similar between successful and unsuccessful inductions over the 20-minute monitoring period (Table 2). Mean time to first effect was 2.5 minutes (SE = 0.3, $n = 64$) for successful inductions and 4.4 minutes (SE = 1.0, $n = 21$) for unsuccessful inductions. Mean time to induction was 7.9 minutes (SE = 0.4, $n = 65$) for successful inductions and 27.8 minutes (SE = 2.2, $n = 19$) for unsuccessful inductions. Mean induction time was 14.0 minutes (SE = 1.9) for a shoulder injection and 11.0 minutes (SE = 1.2) for a rump injection.

We evaluated 7 models (Table 3) and the model: induction $\sim$ ketamine dosage + body-condition index had the greatest $AIC_c$ weight (0.81) and showed that the probability of successful induction increased by about 6.7% with every 1.0 mg/kg increase in ketamine dosage and by about 0.7% with every 1-unit decrease in body-condition index (Fig. 1). The remaining parameters were not included in other models; hence, our results did not support our prediction of greater induction success for shoulder injections.

## DISCUSSION

Minimizing the number of chemical injections required to achieve induction is important for enhancing the efficacy of handling efforts and the safety of animals and researchers. Our analysis indicates that ketamine dosage and body condition influenced ketamine–xylazine immobilization efficacy, such that increasing the ketamine dosage and decreasing body condition increased the probability of successful induction. Increasing ketamine dosage at capture is important because deer mass is often difficult to estimate before handling and deer and handlers would benefit from using a standard dosage for deer in field studies. Although there was only a 0.6 mg/kg difference in mean ketamine dosage between successful and unsuccessful inductions, mean ketamine dosage for successful deer (5.8 mg/kg) more closely approximated a 400-mg injection. DelGiudice et al. (2001) used a mean ketamine dosage of 5.2 mg/kg on wild captured deer during winter, similar to our mean unsuccessful dosage, but stated that deer were often administered booster injections to maintain immobilization for about 82 minutes. Additionally, Mech et al. (1985) used a mean ketamine dosage of 7.4 mg/kg (range = 4.92–11.69; $n = 13$) on predominantly captive deer, but also stated that deer occasionally required supplemental ketamine injections. We recommend that researchers use 400 mg of ketamine with 100 mg xylazine to effectively immobilize wild deer of up to 93.0 kg, particularly if extended handling time ($\geq$45 min) or more stressful capture methods (e.g., rocket nets; Beringer et al. 1996) are used. Ketamine has broad margins of safe

**Table 1.** Mean and standard error (SE) of dosages (mg/kg) and body characteristics of female white-tailed deer (*Odocoileus virginianus*; $\geq$1.5-yr-old) captured in Clover traps and successfully ($n = 65$) or unsuccessfully ($n = 22$) inducted within 15 minutes from first ketamine–xylazine injection, Upper Peninsula of Michigan, USA, January to March 2009–2011. The body-condition index was derived from the residuals of the regression: body mass = −60.82 + 2.85 ln(right hind-foot length); $R^2 = 0.42$, $P < 0.01$, df = 72.

| | Successful | | | | Unsuccessful | | | |
|---|---|---|---|---|---|---|---|---|
| **Characteristics** | ***n*** | $\bar{x}$ | **SE** | **Range** | ***n*** | $\bar{x}$ | **SE** | **Range** |
| Ketamine (mg/kg) | 61 | 5.8 | 0.2 | 3.2 to 9.3 | 20 | 5.2 | 0.3 | 3.3–8.3 |
| Xylazine (mg/kg) | 61 | 1.6 | 0.0 | 1.1 to 2.9 | 20 | 1.5 | 0.1 | 1.1–2.1 |
| Body-condition index | 55 | −1.7 | 0.2 | −20.0 to 24.8 | 19 | 4.8 | 2.3 | 4.2–26.3 |
| Body mass (kg) | 61 | 66.7 | 1.6 | 43.0 to 93.0 | 20 | 71.4 | 2.9 | 48.0–90.0 |

**Table 2.** Mean and standard error (SE) of physiological characteristics of female white-tailed deer (*Odocoileus virginianus*; ≥1.5-yr-old) captured in Clover traps and successfully ($n = 65$) or unsuccessfully ($n = 22$) inducted within 15 minutes from first ketamine–xylazine injection, Upper Peninsula of Michigan, USA, January to March 2009–2011. Characteristics were recorded at about 10-minute intervals.

| | Unsuccessful | | | | | | Successful | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 min | | 10 min | | 20 min | | 0 min | | 10 min | | 20 min | |
| Characteristic | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE | $\bar{x}$ | SE |
| Rectal temperature (°C) | 39.2 | 0.4 | 38.8 | 0.4 | 38.3 | 0.5 | 39.1 | 0.2 | 38.7 | 0.2 | 37.8 | 0.3 |
| | $n = 19$ | | $n = 19$ | | $n = 19$ | | $n = 59$ | | $n = 58$ | | $n = 57$ | |
| Heart rate (beats/min) | 61 | 3 | 55 | 2 | 46 | 3 | 68 | 3 | 60 | 2 | 51 | 2 |
| | $n = 19$ | | $n = 18$ | | $n = 14$ | | $n = 53$ | | $n = 46$ | | $n = 39$ | |
| Respiration (breaths/min) | 38 | 4 | 33 | 4 | 34 | 4 | 33 | 2 | 30 | 2 | 28 | 2 |
| | $n = 19$ | | $n = 19$ | | $n = 17$ | | $n = 58$ | | $n = 55$ | | $n = 47$ | |

dosage (Kreeger and Arnemo 2007) that allow use of standardized doses for immobilizing deer when mass is unknown prior to capture. However, researchers should recognize that deer body condition may vary among seasons and lower chemical doses may be warranted for deer with poor body condition compared with those in better condition (Kreeger and Arnemo 2007). Our results suggest that animal condition can influence deer induction success, because body condition was an influential variable explaining deer induction success. However, because deer in our study area had minimal fat reserves (Duquette et al. 2012) and we found no difference in induction time between injection sites, we suggest that muscle mass likely had a greater influence on deer induction rate than did soft tissue (i.e., subcutaneous body fat).

Our results suggested that xylazine dosage had a negligible effect on deer immobilization efficacy. This was not surprising because, unlike ketamine that causes a cataleptic state, xylazine provides muscle relaxation and is an analgesic that allows animals to remain responsive to external stimuli (Kreeger and Arnemo 2007). We considered induction successful based on ataxia of limbs and lack of eye reflex that would have been more indicative of ketamine rather than xylazine effects. Although we did not vary the absolute dose of xylazine among deer, we believe our mean dosage (1.6 mg/kg) was effective in providing smooth induction of captured deer, particularly because deer were restrained in traps while waiting for the chemicals to take effect. Similar to DelGiudice et al. (2001), who reported an effective mean xylazine dosage of 1.9 mg/kg for deer captured with similar methods during winter, we recommend using xylazine dosage of 1.6 mg/kg for smooth immobilization of deer.

Although we hypothesized that a shoulder injection would provide faster induction, injection site did not influence the probability of successful deer induction. It is unlikely that differences in ketamine dose between injection sites had a pronounced influence on injection site efficacy because the percentages of deer injected with 400-mg and 300-mg ketamine doses were relatively similar between injection sites. Rather, the poor predictive ability of injection site may have been influenced by deer excitation level and weather conditions at time of capture that could have altered the absorption rate of chemicals. Highly excited deer, particularly those captured on colder days, may have absorbed chemicals faster due to greater metabolic rates. In addition, deer in our region often have reduced body condition and fat stores during winter (Mautz 1978) and were likely in relatively poor condition, leading to similar drug absorption rates between rump and shoulder injections.

Following induction, all deer heart and respiration rates and rectal temperatures progressively decreased, likely due to lower chemical metabolism and reduced deer excitation. Most (>95%) deer rectal temperatures remained within reported ranges (37.8–39.2°C; DelGiudice et al. 2001) for

**Table 3.** Model coefficient estimates, standard errors (SE), coefficient 95% confidence intervals, and probability of a greater *t*-value ($P > t$) of successful chemical induction of white-tailed deer (*Odocoileus virginianus*; $N = 87$, ≥1.5-yr-old), Upper Peninsula of Michigan, USA, January to March 2009–2011. Models were selected using Akaike's Information Criterion corrected for small sample size ($AIC_c$) and ranked with $\Delta AIC_c$ and $AIC_c$ weight.

| Model | Parameter[a] | Coeff. | SE | 95% CI | $P > t$ | df | $AIC_c$ | $\Delta AIC_c$ | $AIC_c$ wt |
|---|---|---|---|---|---|---|---|---|---|
| IND ~ log KD + COND[b] | log KD | 6.72 | 3.50 | 0.10 to 14.03 | 0.06 | 65 | 72.92 | 0.00 | 0.81 |
| | COND | −0.07 | 0.03 | −0.14 to −0.01 | 0.02 | | | | |
| IND ~ log XD + COND | log XD | 0.91 | 0.93 | −0.83 to 2.95 | 0.33 | 65 | 75.86 | 2.93 | 0.19 |
| | COND | −0.07 | 0.03 | −0.13 to −0.01 | 0.02 | | | | |
| IND ~ COND | COND | −0.06 | 0.03 | −0.11 to −0.01 | 0.03 | 72 | 83.25 | 10.32 | 0.00 |
| IND ~ log KD | log KD | 6.79 | 2.98 | 1.23 to 13.05 | 0.02 | 80 | 88.97 | 16.04 | 0.00 |
| IND ~ log XD | log XD | 2.10 | 1.47 | −0.62 to 5.20 | 0.15 | 86 | 92.59 | 19.67 | 0.00 |
| IND ~ age class[c] | Yearling | 0.98 | 1.38 | −2.26 to 3.66 | 0.48 | 83 | 101.89 | 28.96 | 0.00 |
| | Prime-age | −0.11 | 1.29 | −3.25 to 2.36 | 0.94 | | | | |
| | Late-age | 0.60 | 1.29 | −2.55 to 3.10 | 0.64 | | | | |
| IND ~ IS | IS | 0.13 | 0.50 | −0.85 to 1.10 | 0.80 | 85 | 104.01 | 31.09 | 0.00 |

[a] Response is induction (IND) and predictor parameters include log-transformed xylazine (log XD) and log-transformed ketamine dosage (log KD), body-condition index (COND), age class, and injection site (IS).
[b] COND estimated from the residuals of the regression eq.: body mass = −60.82 + 2.85 ln(right hind-foot length); $R^2 = 0.42$, $P < 0.01$, df = 72.
[c] Deer age classes include yearling (1.5-yr-old), prime-age (2.5- to 6.5-yr-old), or late-age (7.5- to 15.5-yr-old; Verme 1969).

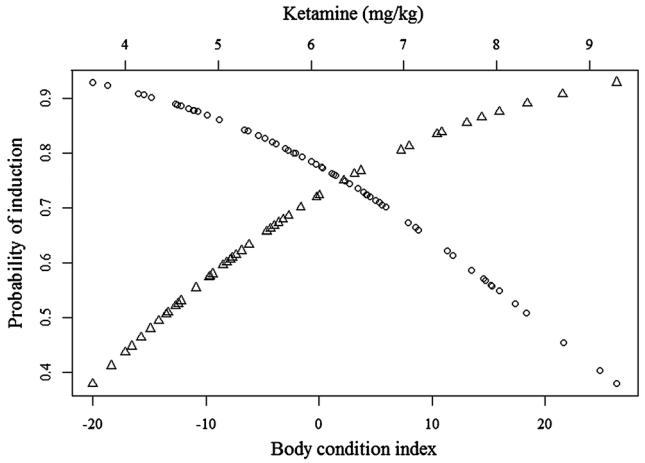


**Figure 1.** Influence of ketamine (100 mg/ml) and body-condition index on the probability of successful chemical immobilization of female white-tailed deer (*Odocoileus virginianus*; $N = 87$, ≥1.5-yr-old), Upper Peninsula of Michigan, USA, January to March 2009–2011. Immobilization was considered successful if achieved ≤15 minutes from first ketamine–xylazine injection and body condition was estimated from the residuals of the regression equation: body mass = −60.82 + 2.85 ln(right hind-foot length); $R^2 = 0.42$, $P < 0.01$, df = 72. Triangles are ketamine and circles are body-condition index.

ketamine–xylazine immobilization and were as expected based on known ketamine–xylazine effects, such as inhibition of thermoregulation (DelGiudice et al. 2001, Kreeger and Arnemo 2007) and respiration (Presnell et al. 1973, Golightly and Hofstra 1989). However, one deer dropped to 33.1° C about 20 minutes post-induction, but recovered normally following yohimbine injection. Therefore, we considered our effective ketamine–xylazine doses satisfactory for field-based deer capture because they produced induction in ≤15 minutes for 75% of deer and allowed ample time (≥45 min) to complete sampling and handling procedures safely.

## MANAGEMENT IMPLICATIONS

Comparable to previous studies (e.g., Kreeger et al. 1986; DelGiudice et al. 2001, 2005), 300 mg or 400 mg of ketamine mixed with 100 mg of xylazine were effective in immobilizing deer, but our results suggest a dose of 400 mg would provide greater efficacy. Researchers should anticipate the excitation level of captured deer and consider the potential range of deer body mass in their study areas before capture when deciding whether a greater ketamine dosage is required, particularly because deer body condition had a strong influence on the probability of successful induction of deer in our study. Regardless, we recommend using a ketamine dosage of 5.8 mg/kg and xylazine dosage of 1.6 mg/kg for successful induction with one intramuscular injection, based on the data from our female deer captured in Clover traps during winter.

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