Wildlife Society Bulletin 38(4):767–772; 2014; DOI: 10.1002/wsb.470

*Original Article*

# How Hot is Too Hot? Live-Trapped Gray Wolf Rectal Temperatures and 1-year Survival

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**ABSTRACT** The ability of physically restrained and anesthetized wolves to thermoregulate is lessened and could lead to reduced survival, yet no information is available about this subject. Therefore, we analyzed rectal temperatures related to survival 1 year post-capture from 173 adult (non-pup) gray wolves (*Canis lupus*) captured in modified foot-hold traps for radiocollaring during June–August, 1988–2011, in the Superior National Forest of northeastern Minnesota, USA. The maximum observed rectal temperature ("maxtemp," ° F, ° C) in each wolf during capture ($\bar{x} = 104.0, 40.0$; SD = 2.0, 1.1; min. = 95.9, 35.5; max. = 108, 42.2) was not a significant predictor of survival to 1 year post-capture. Although no weather or morphometric variable was a significant predictor of maxtemps, wolves initially anesthetized with ketamine–xylazine rather than telazol®–xylazine averaged higher maxtemps. This information does not fully address possible effects of high body temperatures related to live-capture and handling of wolves, but it does provide a useful waypoint for future assessments of this relationship and a reassurance to wildlife practitioners that the maxtemps observed in our study did not appear to affect 1-year survival. Published 2014. This article is a U.S. Government work and is in the public domain in the USA.

**KEY WORDS** anesthesia, *Canis lupus*, gray wolf, hyperthermia, rectal temperature, survival, trapping.

The ability of physically restrained and anesthetized animals to thermoregulate is lessened and could lead to reduced survival (Kreeger and Arnemo 2012). Therefore, we assessed survival related to maximum observed rectal temperatures during captures of gray wolves (*Canis lupus*) live-trapped during a long-term study in the Superior National Forest of northeastern Minnesota, USA (Mech 2009).

Mammalian rectal temperatures generally range from 99.5 to 104 °F (37.5–40 °C) (Kreeger and Arnemo 2012). Mammals may experience cell damage at rectal temperatures of 104 °F (40 °C); temperatures of >106.0 °F (>41.1 °C) are considered hyperthermic medical emergencies; temperatures of 108 °F (42.2 °C) can cause "residual impairment"; and direct mortality is likely at 110 °F (43.3 °C) (Kreeger and Arnemo 2012). In general, hyperthermia and heat injury to cells can result in notable pathology, including brain, liver, and pancreatic damage; kidney failure; respiratory distress; spontaneous bleeding and blood clotting complications; immune compromises; damage or death to portions of the intestine due to hypoxia; cardiovascular collapse and death (Bouchama and Knochel 2002).

Dogs dissipate heat through radiation and convection from body surfaces and by evaporative and convective heat loss through panting (Ederstrom 1954, Nemoto and Frankel 1970, Bruchim et al. 2006). Increased air temperature and humidity reduce a dog's ability to cool by evaporative heat loss (Flournoy et al. 2003, Bruchim et al. 2006). Although carefully controlled whole-body hyperthermia in dogs can be tolerated to 108.1 °F (42.3 °C) (Oglesbee et al. 1999), and canid brains are intrinsically resistant to sub-lethal temperatures (Oglesbee et al. 2002), permanent brain damage in dogs can develop at temperatures as low as 105.8 °F (41.0 °C) (Flournoy et al. 2003).

Trapped wolves cannot move out of sunlight or to obtain water and are likely stressed, resulting in increased metabolic demand, thus increasing risk of hyperthermia. Anesthetized wolves also have reduced thermoregulatory ability, at least in part because they cannot pant to cool themselves (Kreeger and Arnemo 2012) and potentially because of other drug-induced changes. Some effects (potentially related to thermoregulation) of commonly used drugs to chemically immobilize wolves include convulsions, seizures, muscle rigidity, tachycardia, bradycardia, hypo and hypertension, cardiac arrhythmias, pulmonary edema, respiratory depression, and hypersalivation (Gray et al. 1974; Kreeger et al. 1987, 1989, 1990*b*; Plumb 2005; Kreeger and Arnemo 2012).

Whereas "normal" rectal temperatures of live-trapped, anesthetized wolves are 101.5–102 °F (38.6–38.9 °C) (and Kreeger et al. 1990*a* reported means of unanesthetized wolf body temperatures from 103.3 to 104.3 °F, 39.60 to 40.17 °C), it is not uncommon for rectal temperatures to reach 106.0 °F (41.1 °C) if a wolf struggles much when trapped (T. J. Kreeger, retired Wyoming Game and Fish Department,

Received: 30 December 2013; Accepted: 15 April 2014
Published: 13 August 2014

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personal communication). Domestic dog core temperatures are generally well-reflected by rectal temperatures (Shapiro et al. 1973, Greer et al. 2007) and some of our captured wolves exhibited rectal temperatures ≥104 °F (≥40 °C). Thus, we were interested in possible lethality of high rectal temperatures, but no information is available on this subject. We could not examine sub-lethal potential impacts of hyperthermia to cognition, foraging, reproduction, behavior, etc. However, our hypothesis was that these potential effects of hyperthermia could result in non-immediate mortality. Thus, we examined the relationship between a wolf's maximum, observed rectal temperature and its survival to 1 year post-capture (an arbitrary, yet reasonable period).

We were also interested in factors that might contribute to higher rectal temperatures, so we assessed weather variables related to air temperature and evaporation efficiency (Bruchim et al. 2006), as well as wolf size and initial drug combinations.

## STUDY AREA

Our study area comprised 2,060-km$^2$ in the Superior National Forest, Minnesota, USA (48°N, 92°W; see Nelson and Mech 1981 for a detailed description). Temperatures rarely exceeded 35 °C. Elevations ranged from 325 m to 700 m above sea level and include swamps, uneven upland, and rocky ridges (Mech 2009). Vegetation was predominately conifers (e.g., jack pine [*Pinus banksiana*], white pine [*P. strobus*], red pine [*P. resinosa*], black spruce [*Picea mariana*], white spruce [*P. glauca*], balsam fir [*Abies balsamea*], white cedar [*Thuja occidentalis*], and tamarack [*Larix laricina*]) in the forest overstory and was interspersed with white birch (*Betula papyrifera*) and quaking aspen (*Populus tremuloides*) due to logging and fires (Mech 2009; see Heinselman 1993 for a detailed description).

During 1988–2011, mean wolf density was 31/1,000 km$^2$ (Mech 2009 and authors' unpublished data). Generally, in the northeastern portion of our study area the wolf's primary prey was moose (*Alces alces*) and in the southwestern portion, white-tailed deer (*Odocoileus virginianus*; Frenzel 1974; Nelson and Mech 1981, 1986; Mech 2009).

## METHODS

We captured wolves with modified foot-hold traps (either Newhouse 14 or Livestock Protection Company's EZ Grip 7) from June to August 1988–2011 (Mech 2009). Traps were baited with standard natural and commercial baits and lures. Traps were generally sited along logging roads and checked at least daily. We followed guidelines of the American Society of Mammalogists (Gannon et al. 2007) during capture and processing. We anesthetized all adult trapped wolves (hereafter, "wolves" refers to all non-pup wolves) with a standard dose of 250 mg ketamine (Ketaset®, ketamine hydrochloride; Fort Dodge Animal Health, Fort Dodge, IA; 1988–1991) or 286 mg telazol® (tiletamine hydrochloride and zolazepam hydrochloride; Pfizer, New York, NY, and Fort Dodge Animal Health; 1992–2011) and 37 mg xylazine (Anased®; Llyod Laboratories, Shenandoah, IA) given intramuscularly via a pole syringe (approximate length 4 feet [1.2 m]). An additional 100–200 mg of ketamine was hand-injected intramuscularly if required.

We placed wolves on a light-weight mesh weighing blanket during processing, positioned laterally or sternally. We weighed wolves to the nearest 0.45 kg (1 lb), collected blood (0–28 cubic centimeter [cc]) and other specimens (sometimes scat and hair) and morphological measurements (including height measured in cm as the length of a fully straightened front leg from the dorsal tip of the scapula to the distal end of a middle toe pad and body length measured in cm as the contour from the nose tip to the base of the tail), applied ear tags, and fit with a radiocollar that pulsed approximately 3 times as rapidly after 4 hours of inactivity (Telonics, Inc., Mesa, AZ). We administered penicillin (6 cc hand-injected intramuscularly) and 0.125 mg/kg yohimbine (Yobine®; Llyod Laboratories), which is an alpha-2 sedative antagonist (intravenously if possible, otherwise intramuscularly). Beginning in 2000, we estimated wolf age by tooth wear comparing with the chart in Gipson et al. (2000). Prior to 2000, we assigned a known-minimum age of 1 year to wolves and updated each wolf's known-minimum age if a wolf was later recaptured. We handled wolves for approximately 1 hour.

Immediately after we anaesthetized and released wolves from the trap, we obtained rectal temperatures using standard, digital, thermometers that displayed °F. If the temperature was within our desired range (98–103 °F, 36.7–39.4 °C), we checked it approximately every 15 minutes until giving yohimbine. If the temperature was outside this range, we applied cooling (see below) or heating measures, ceased additional drug administration until any temperature problem was corrected, and rechecked the temperature about every 5 minutes until it was within the desired range (followed by checks about every 15 min). If the temperature was extreme enough to be considered an emergency (e.g., <94.0 °F or >106.0 °F, <34.4 °C or >41.1 °C; Kreeger and Arnemo 2012) and we could not correct it within 15 minutes, then we generally reversed the xylazine with yohimbine. Although we usually recorded each temperature throughout processing (°F), we did not always record temperatures within already-recorded ranges, especially when mitigating rectal temperatures and completing high-priority processing. Thus, we lacked data on rate of recovery from hyperthermia. We were also unable to determine the duration of exposure to the maximum temperature observed, so we used the maximum, observed rectal temperature (hereafter, maxtemp) during each wolf processing for this analysis.

We determined survival to 1 year post-capture (hereafter, survival) by following radiocollared wolves generally weekly via aerial telemetry. We excluded wolves whose fate was unknown 1 year post-capture (e.g., malfunctioning radiocollar or possible dispersal). We only included one capture per wolf. For recaptured wolves we used the capture with the highest maxtemp. We excluded 3 wolves whose deaths were not temperature-related (1 wolf euthanized by a conservation

officer, 1 that died during capture, and 1 that died 3 days after capture).

We used 2-tailed *t*-tests assuming unequal variance to assess gender and drug differences in temperature during capture and in survival. We used logistic regression to assess maxtemp as a continuous predictor of survival to 1 year post-capture, our binary response variable. Because of a slight negative skew, we transformed the predictor maxtemp to normality using log (115-maxtemp °F). We assessed leverage and influence (Cook's Distance, values of <0.2 indicated acceptable influence) of each case on the estimated regression coefficients. To visualize potential trends and thresholds in our binary response variable (survival), we examined the plot of a lowess-smoothed trend of survival-versus-maxtemp (Fig. 1).

We used multiple linear regression to assess the importance of various weather (max. daily temp, average daily temp, average dew point), morphometric (gender, weight, body length, and height) and drug combination (ketamine–xylazine or telazol®–xylazine) variables on maxtemp (Table 1). We obtained weather data for station KELO (Ely, MN) from http://www.wunderground.com/history/ (accessed on 3 Dec 2013) for June 1988–August 2011. Ely was 11–61 km from our trapping area. We used dew point rather than humidity upon advice from the Minnesota State Climatology Office because it more closely relates to the potential for heat dissipation. We only allowed variables not highly correlated ($r < 0.50$) to be assessed at the same time in the multiple linear regression and assessed leverage and Cook's Distance (values <0.2 indicated acceptable influence) to examine the effects of potential outliers on the outcome of the regression.

We considered all statistical tests significant at $\alpha = 0.05$. We conducted *t*-tests in Excel (version 14.0.7106.5003, Microsoft® Office Professional Plus 2010; Microsoft Corp., Redmond, WA), regressions and leverage and Cook's Distance evaluations in Arc version 1.06 (Cook and Weisberg 1999) and plotted variables and lowess-smoothed lines in R version 3.0.2 (2013-09-25; Copyright 2013 The R Foundation For Statistical Computing; http://www.r-project.org/foundation).

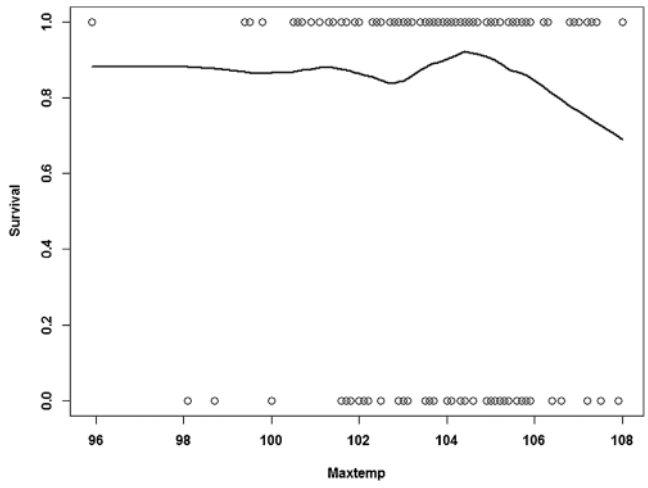


**Figure 1.** Survival to 1 year post-capture versus maximum, observed rectal temperature (maxtemp; 95.9–108 °F, 35.5–42.2 °C) in gray wolves ($n = 173$) captured in the Superior National Forest of northeastern Minnesota, USA, during June–August 1988–2011 (0 = died, 1 = survived). The line is a lowess-smoothed trend.

## RESULTS

We analyzed the maximum rectal temperatures (°F, °C; $\bar{x} = 104.0$; 40.0; SD = 2.0, 1.1; min. = 95.9, 35.5; max. = 108, 42.2) from 81 male and 92 female wolves captured during June–August 1988–2011. Mean maxtemp (°F, °C) in males (103.9, 40.1; SD = 1.9, 1.0) was not significantly different ($P = 0.06$) from that in females (103.5, 39.8; SD = 2.1, 1.1). Of the 173 wolves, 124 (72%) survived ≥1 year post-capture (Table 2). Wolves anesthetized with ketamine–xylazine ($n = 38$) rather than telazol®–xylazine ($n = 135$) averaged higher temperatures ($P < 0.001$; °F, °C; $\bar{x} = 104.8$, 40.5 and 103.7, 39.8 and; SD = 1.5, 0.8 and 2.0, 1.1, respectively). Survival did not significantly differ ($P = 0.50$) between males (0.73, SD = 0.4) and females (0.71, SD = 0.5) or between drug combination ($P = 0.22$; telazol®–xylazine, $\bar{x} = 0.74$, SD = 0.4; ketamine–xylazine $\bar{x} = 0.63$, SD = 0.5).

The transformed maxtemp did not predict survival ($P = 0.89$). A summary of survival to 1 year post-capture categorized by temperatures similarly lacked a clear pattern (Table 2). We detected no data points with high leverage or unacceptably high influence.

The plot of survival-versus-maxtemp (Fig. 1) with a lowess-smoothed trend line revealed a potential survival decline beyond the range of observed variation at approximately 106.5 °F (41.4 °C). Based on this information, we conducted another logistic regression using only maxtemps of ≥106 °F (≥41.1 °C) ($n = 18$) to assess a potential maxtemp beyond which survival was negatively influenced. But, as with the full data set, maxtemp did not predict survival ($P = 0.58$). The plot of survival-versus-maxtemp for values ≥106 °F (≥41.1° C) with a lowess-smoothed trend line revealed significant variability and a non-continuous decline (Fig. 2). Notably, the wolf exhibiting the highest maxtemp in our analysis (108 °F, 42.2 °C) survived.

Of all the wolves captured during the study, female wolf 7077 exhibited the highest maxtemp, 108.9 °F (42.7 °C). We did not include her in the regression analysis because we could not determine her survival 1 year post-capture because of a lost radio signal after 1 month.

We also did not include 2 adult wolves with maxtemps recorded as "108+" on capture data sheets (≥108 °F, ≥42.2 °C) in this analysis because they were captured during September. (We have a different trap-checking regimen outside of Jun–Aug). Nevertheless, their histories are informative. Female wolf 317 survived 5 years post-capture, and male wolf 671 survived 353 days post-capture. Both wolves died of unknown causes.

Because wolf height and weight were highly correlated ($r = 0.66$), we excluded height from the multiple linear regression assessing the importance of weather, morphometric, and drug variables on maxtemp. All 3 weather

**Table 1.** Descriptive summaries of variables we assessed for potential relation to the maximum observed rectal temperatures of wolves live-trapped in the Superior National Forest, Minnesota, USA, June–August, 1988–2011.

| Variable (units) | $\bar{x}$ | Min., max. | SD | $n$ |
|---|---|---|---|---|
| Max. daily air temp (°F, °C) | 75.4, 24.1 | 59.0, 93.0; 15.0, 33.9 | 7.0, 3.9 | 171 |
| Average daily air temp (°F, °C) | 64.9, 18.3 | 49.0, 87.0; 9.4, 30.6 | 6.4, 3.6 | 170 |
| Average daily dew point (°F, °C) | 55.1, 12.9 | 34.0, 72.0; 1.1, 22.2 | 6.9, 3.8 | 171 |
| Body weight, combined genders (kg[a]) | 31.4 | 20.0, 44.5 | 5.0 | 169 |
| Body weight, males (kg) | 34.9 | 27.7, 44.5 | 3.8 | 78 |
| Body weight, females (kg) | 28.4 | 20.0, 40.8 | 3.8 | 91 |
| Body length (cm) | 122.0 | 87.0, 176.0 | 12.2 | 159 |
| Height (cm) | 76.5 | 57.0, 91.0 | 4.9 | 159 |

[a] We measured wolf weights in the field to the nearest 1 lb and later converted them to kilogram.

variables were correlated (all $r > 0.50$), so we entered each into the regression separately and assessed for the best-model fit. After we removed a single data point with unacceptably high influence and leverage (on 7 Jul 1988, the max. and average air temps were 93 °F, 33.9 °C and 87 °F, 30.6 °C, respectively, both of which were our most extreme values), the only significant variable ($P = 0.002$) was drug combination (ketamine–xylazine correlated with higher maxtemps). This significance accorded with the $t$-test results indicating wolves given ketamine–xylazine had higher mean maxtemps (difference in means = 1.1 °F, 0.7 °C). However, the regression explained little variation in maxtemp ($r^2 = 0.05$). Notably, only 38 (22%) wolves were anesthetized with ketamine–xylazine relative to 135 with telazol®–xylazine (78%).

## DISCUSSION

We detected no significant influence of rectal temperatures during captures on wolf survival to 1 year post-capture. Variations in duration of exposure to extreme temperatures likely influence survival in different ways (Shapiro et al. 1973). Because we could not examine high-temperature duration, we recommend research to better understand its importance.

Because we only assessed survival 1 year post-capture, we could only detect impacts that influenced mortality within 1 year. If any other effects discussed earlier were not severe enough to result in mortality 1 year post-capture they would not be reflected in our results. There were too many confounding differences in territory sizes, weather post-capture, social role, differences in telemetry access, and effort, etc., that precluded us from considering movements post-capture as an index to these non-lethal effects.

Nevertheless, we can conclude that short-term rectal temperatures up to 106 °F (41.1 °C) do not affect wolf survival to 1 year. Above 106 °F (41.1 °C), the lowess-smoothed trend line for survival generally (Fig. 1)—but not consistently (Fig. 2)—declined beyond the amount of observed variation in the rest of the ranges of temperatures observed. Only 10% ($n = 18$) of our maxtemps were ≥106 °F (≥41.1 °C), so the small sample using only these data (including only one maxtemp of ≥108 °F, ≥42.2 °C) may have influenced the lack of significance in that analysis. Even in the 4 wolves with maxtemps of ≥108 °F, 42.2 °C, there was no clear pattern in survival to 1 year.

Whereas gray wolves generally cannot survive temperatures of 110 °F (43.3 °C), some can, albeit with significant risk of dying days later (T.J. Kreeger, retired Wyoming Game and Fish Department, personal communication). Thus, we

**Table 2.** Maximum observed rectal temperatures of wolves live-trapped in the Superior National Forest, Minnesota, USA, June–August, 1988–2011, and survival to 1 year post-capture.

| Temp °F (°C)[a] | $N$ | No. survived | % survival |
|---|---|---|---|
| 95.0–95.9 (35.00–35.50) | 1 | 1 | 100 |
| 98.0–98.9 (36.67–37.17) | 2 | 0 | 0 |
| 99.0–99.9, (37.22–37.72) | 4 | 4 | 100 |
| 100–100.9 (37.78–38.28) | 7 | 6 | 86 |
| 101–101.9 (38.33–38.83) | 13 | 8 | 62 |
| 102–102.9 (38.89–39.39) | 16 | 11 | 69 |
| 103–103.9 (39.44–39.94) | 32 | 21 | 65 |
| 104–104.9 (40.00–40.50) | 45 | 38 | 84 |
| 105–105.9 (40.56–41.06) | 36 | 24 | 67 |
| 106–106.9 (41.11–41.61) | 6 | 4 | 67 |
| 107–107.9 (41.67–42.17) | 10 | 6 | 60 |
| 108 (42.22) | 1 | 1 | 100 |

[a] We observed no wolves with max. rectal temp in the range of 96.0–96.9 °F (35.56–36.06 °C) or 97.0–97.9 °F (36.11–36.61 °C).

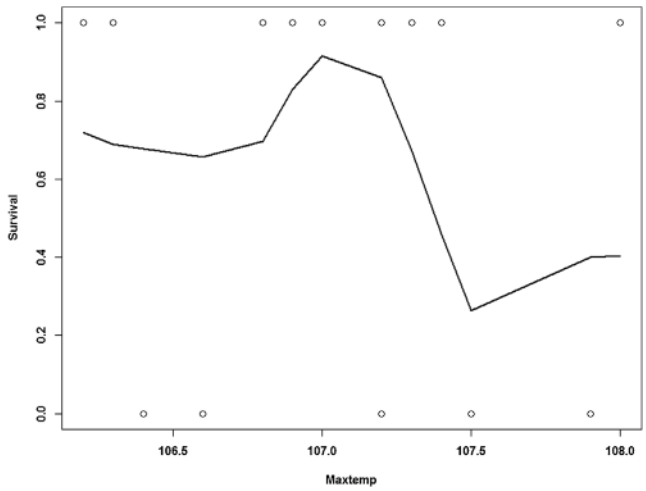


**Figure 2.** Survival to 1 year post-capture versus maximum observed rectal temperature (maxtemp; 106.0–108 °F, 41.1–42.2 °C) in gray wolves ($n = 18$) captured in the Superior National Forest of northeastern Minnesota, USA, during June–August 1988–2011 (0 = died, 1 = survived). The line is a lowess-smoothed trend.

suspect that between 106.5 and 110 °F (41.4–43.3 °C) a temperature exists beyond which survival is reduced.

Although we assessed several weather and morphometric variables, none was significant. Probably this was because 1) exposure to sunlight is more important than air temperatures; 2) our processing times of day varied; and 3) most of our wolves were thin. We usually did not trap when temperatures exceeded 85 °F (29.4 °C), so cases with hotter air temperatures were few. (Only 12 days out of 173 captures had max. temperatures >85 °F, >29.4 °C). Wolves anesthetized with ketamine–xylazine rather than telazol®–xylazine had higher maxtemps, although the difference was not great enough to result in any detectable survival consequences.

Although wolves can survive rectal temperatures (duration unknown) of 106.0 °F (41.1 °C), we agree with Kreeger and Arnemo (2012) that wildlife practitioners should begin cooling when temperatures exceed 104 °F (40.0 °C). Small temperature rises can be corrected merely by moving the animal to shade; or administering cool-water enemas; or applying cool-water or alcohol on the abdomen, axillae, and inguinal areas and fanning; wrapping ice packs in a thin towel and placing in the axillae and inguinal areas and around the head; administering subcutaneous fluids; positioning the wolf sternally on cooler ground; ceasing additional administration of anesthetics; and avoiding muzzles or head covers that reduce evaporative and convective heat loss. Avoiding hot and humid weather and trapping conditions that may expose trapped animals to hyperthermia are important, and Kreeger and Arnemo (2012) give other measures to use for treating hyperthermia. Although research indicates that wolves can be safely anesthetized with ketamine–xylazine or telazol®–xylazine (Kreeger et al. 1987, 1990*b*, 1995; Kreeger and Arnemo 2012), based on our results, we recommend exercising caution and initially anesthetizing with telazol®–xylazine rather than ketamine–xylazine when hyperthermia is a concern.

In addition to mitigating rectal temperatures once the wolf is hyperthermic, decisions regarding trap location can also help minimize wolf overheating, such as setting traps in areas where there is sufficient shade (consider sunlight penetration during midday and the removal of vegetation that a trapped wolf can chew or tear down with a drag chain) and sufficient ground material to catch a drag hook and therefore, the wolf, in the shaded area. Similarly, setting traps where human use is restricted or reduced can also help minimize wolf overheating because repeated interactions with humans while a wolf is trapped can cause stress and potential hyperthermia.

Whether to trap at all based on ambient temperatures must also be considered. Generally, when ambient summer-temperature highs reached 29.4 °C (85 °F), we either pulled the entire trapline, checked traps at least twice daily to prevent wolves from remaining in a trap during the hottest part of the day, or covered the traps to prevent capture during the hottest part of the day. To cover our traps, we used a small square board (slightly larger than the circumference of the jaws themselves) that rested evenly on all parts of the jaws and was weighted with a rock with vegetation (and sometimes sifted soil) camouflaging the board and rock. Covered traps must still be checked daily in the unlikely event that a board might be displaced and an animal become trapped. Regardless of the strategy to mitigate wolf overheating during live-trapping, continued assessment of its efficacy and practitioner flexibility are of utmost importance to ensure survival of physically restrained and anesthetized wolves.

## ACKNOWLEDGMENTS

This project was supported by the U.S. Geological Survey. We thank M. E. Nelson and numerous volunteer technicians; T. J. Kreeger for helpful discussions; C. "Kit" Bingham for statistical assistance; L. Schmidt and 4 anonymous referees; and P. Boulay for information on weather variables. Any mention of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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*Associate Editor: Rodgers.*