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Rate of Cooling in a Moose (*Alces alces*) Carcass

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ABSTRACT: Postmortem body temperature is used to estimate time of death in humans, but the available models are not validated for most nonhuman species. Here, we report that cooling in an adult female moose (*Alces alces*) equipped with a rumen temperature monitor was extremely slow, with a rumen temperature of 27–28 C as late as 40 h postmortem.

Body temperature is used in forensics for estimating time of death in humans (Lyle and Cleaveland 1956; Kaliszan 2013); however, extrapolation of these methods to estimate cooling of animal carcasses is difficult, especially because many factors, including species differences affect this process (Munro and Munro 2013; Brooks 2016). Species-specific temperature curves have been used to produce models predictive of time of death in certain species, including white-tailed deer (Oates et al 1984; Hadley et al. 1999). This knowledge would be useful to expand to other species for studies on causes of animal mortalities and for forensic cases.

Although models for humans have been applied to wildlife, we propose that ruminants, with postmortem rumen bacterial activity, have a death temperature curve that is not comparable to humans (Nation and Williams 1989). In cattle, body temperature rises after death, as rumen fermentation continues. Bacteria, including *Clostridium* spp., produce gas-driven bloating of the carcass, stretching the skin and increasing body temperature. As decomposition progresses, gas production decreases (Nation and Williams 1989). Algor mortis, the gradual cooling of the cadaver to ambient temperature, depends on temperature of the body at death, body mass, and environmental factors, such as ambient temperature, wind, and precipitation (Zachary and McGavin 2013).

In February 2015, eight adult female moose (*Alces alces*) in Öland, Sweden (56°43′N 16°39′E) were fitted with global positioning system (GPS) collars, collar thermometers, and rumen temperature loggers with a mortality detector (Vectronic Aerospace GmbH, Berlin, Germany). The capture and device deployment were as previously described (Evans et al. 2012; Minicucci et al. 2018). Rumen temperature (T_r), collar temperature (T_c), and GPS locations were recorded at 15-min intervals.

We report the death of one of the instrumented female moose, estimated to be 6 yr old at capture on 10 February 2015. Its calf was found dead on 18 May 2015. The following year, the moose decreased its movement distinctly on 22 March 2016 and dropped it further on 23 March 2016. It died on 7 April 2016 at 1610 hours due to unknown reasons. The movement change was identified with behavioral change point analysis (Gurarie et al 2009) that analyzed the animal's speed, variation in speed, and the duration of the directed movement (Fig. 1A) and identified breakpoints when a change occurred in all three components. The time of death was pinpointed by the mortality detector. On inspection, the site where the animal was found was open, with grass and willow bushes and direct sun exposure.

To predict cooling, we used the formula as adapted previously (Horning and Mellish, 2009):

$$Q = \frac{T_{\text{core}} - T_{\text{ambient}}}{T_0 - T_{\text{ambient}}} = 1.25e^{Bt} - 0.25e^{5Bt}.$$

We replaced core temperature (T_{core}) with rumen temperature (T_r), as being similar to

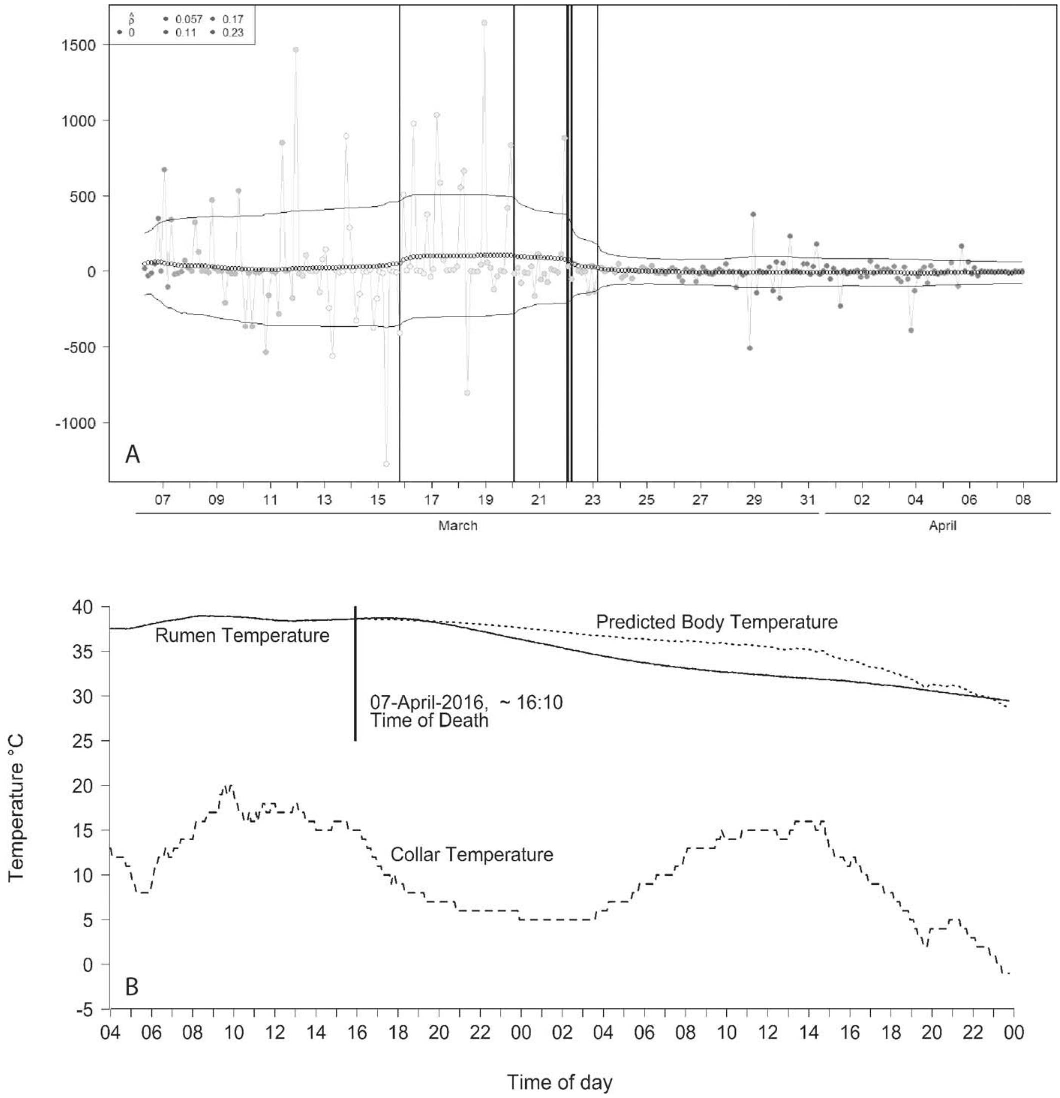

FIGURE 1. (A). Movement patterns of a female moose (*Alces alces*) equipped with a temperature data logger in the rumen. Behavioral change point analysis identification of different periods of movements between 7 March and 8 April. Break points in movement were identified when a simultaneous change occurred in speed, variation, and duration of movement (vertical lines). Each point is a position: x axis represents the time, y axis shows the velocity (μ, dots) and the variance (σ, lines) in meters per 3-h interval. We found a strong decrease in in the variance of velocity about 2 wk before she died. (B). The decline in rumen temperature (T_r; dotted line) in the 36 h after death in a female moose (*Alces alces*). The body temperature started declining approximately 2 h after death and continued gradually over the 36 h pictured. The model body temperature (T_m; solid line) shows predicted cooling rates. The ambient temperature (dashed line) as measured by the sensor on the collar is T_c.

T_{core} in moose (Herberg 2017). We replaced the ambient temperature ($T_{ambient}$) with collar temperature (T_c), which has been validated as a proxy for $T_{ambient}$ (Ericsson et al. 2015). The T_r at the time of death is T_0 (38.6 C), t is the hours since death, and B is the Newtonian cooling coefficient described by

$$B = -1.2815 \times (C \times \text{mass})^{-0.625} + 0.0284,$$

where C is the correction factor (0.75) for moving air (Horning and Mellish 2009). Body mass was estimated by field personnel to be

300 kg. We adapted this formula to give the predicted core temperature for a given t since death, with T_m as the model-predicted core body temperature:

$$T_m = (1.25e^{Bt} - 0.25e^{5Bt})(T_0 - T_c) + T_c.$$

As illustrated in Figure 1B, postmortem cooling in a large animal is extremely slow with a T_r of 27–28 C nearly 40 h after death at $T_{ambient}$ 5–15 C. Slow cooling contributes to carcass decomposition and may interfere with accurate interpretation of gross and microscopic changes. For a meaningful necropsy, relevant for determination of cause of death, including disease, nutrition, or anthropogenic factors, cooling of the carcass should be hastened by skinning of the carcass, removal of the gastrointestinal tract, refrigeration, field necropsy, or sampling of organs at the site of death. In forensic cases, deep body temperature may be used, together with ambient temperature, to estimate the time from death by solving for time (t). Indeed, models on the basis of body mass and ambient conditions have been applied to other species (Horning and Mellish, 2009).

Interestingly, T_r decreased faster than the model until slowing 24 h after death of the moose. This was contrary to previous reports that rumen fermentation causes an immediate increase in T_r (Nation and Williams, 1989). The lack of movement and presumed lack of foraging before death may have affected the ruminal microbial flora. In hunted animals, the temperature of the carcass can be used to assess if the time of death (e.g., as given by the hunter) is reasonable.

We documented the postmortem cooling rate in a dying moose. The results are relevant for forensic cases, including legal or illegal hunting and traffic accidents and management issues (inspections of shot animals, disease outbreak investigations, or marking-related deaths). More data should be collected to make a model as previously done for white-tailed deer (Cox et al 1994; Hadley et al. 1999,). We suggested the importance of cooling, skinning, and eviscerating large animals to preserve the carcasses to enable a proper necropsy.

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