Appendix S1 for
Thermal biology and growth of bison (Bison bison) along the Great Plains: examining four theories of endotherm body size

Ecosphere

Jeff M. Martin and Perry S. Barboza

This PDF file includes

Contents
Materials .......................................................................................................................... 2
Methods .......................................................................................................................... 2
Figures .......................................................................................................................... 5
Tables ............................................................................................................................. 6
Literature Cited in Appendix S1 .................................................................................. 10
Video S1 (separate file) .............................................................................................. Error! Bookmark not defined.

List of Figures
Fig. S1. Boxplot of winter and summer range of temperature for each locality. Solid red circle indicates daily mean temperature on the day of the summer visit, whereas solid blue triangle indicates daily mean temperature on the day of the winter visit. Numbers refer to site number. .. 5

List of Tables
Table S1. Summary table of body surface temperature (°C) in a multilevel mixed effects general linear model of black globe temperature (TGlobe; °C) interacting with season, wet bulb globe temperature (TWBGT; °C) interacting with season, and wet bulb globe temperature. Abbreviations: β, beta coefficient; SD, standard deviation; SE standard error. Cross-validation support metrics using k(10)-fold: pseudo-R² = 0.61, RMSE = 10.3, N = 779 individuals, n = 19 groups by site. Random effects (site) explained 0.26% of variance. ............................................................................................................. 6
Table S2. Summary table of ordinary least squares regressions of total body surface heat loss (Q; W) over estimated body mass (BMₐ; kg) and log of absolute value of body surface heat loss (log₁₀(Q); log₁₀(|W|)) over log of estimated body mass (log₁₀(BMₐ); log₁₀-kg). Abbreviations: β, beta coefficient; SE standard error. W: Adj. R² = 0.31, RMSE = 79.1, N = 694 individuals; log-|W|: Adj. R² = 0.36, RMSE = 0.13, N = 694 individuals. ........................................................................................................ 6
Table S3. Summary table of total body surface heat loss (W) in an ordinary least squares model of growth rate (kg•y⁻¹). Abbreviations: β, beta coefficient; SD, standard deviation; SE standard error. W: Adj-R² = 0.28, RMSE = 58.6, n = 16 groups by site. ........................................................................................................ 6
Table S4. Summary table of heat flux (W•m⁻²) in a multilevel mixed effects general linear model of latitude interacting with season and site as a random effect. Abbreviations: β, beta coefficient; SD, standard deviation; SE standard error. Cross-validation support metrics using k(10)-fold: pseudo-R² = 0.12, RMSE = 64.6, N = 343 individuals, n = 19 groups by site. Random effects (site) explained 0.61% of variance.................................................................................................................. 7
Table S5. Parameters of bison body size, body and eye temperature, and reflectance of hair and bare skin................................................................. 7
Table S6. Emissivity (ε) of selected materials used in this study.................................. 9
List of Equations

Equation 1. \( k = d/I \) ................................................................. 3
Equation 2. \( q_{sens} = kd(T_b - T_s) \) .................................................. 3
Equation 3. \( q_{tot} = q_{rad} + q_{conv} + q_{sens} \) .................................. 3
Equation 4. \( Q = SA \times q_{tot} \) .......................................................... 3
Equation 5. \( d_{winter} = 0.0221 \text{ subcutaneous fat} + 0.015 \text{ skin thickness} + 0.0413 \text{ winter hair coat} \) .............................................. 4
Equation 6. \( d_{summer} = 0.0221 \text{ subcutaneous fat} + 0.015 \text{ skin thickness} + 0.001 \text{ summer hair coat} \) .................................................. 4

Materials

**Ethical approval and research permits.**
All procedures performed in studies involving animals were in accordance with the ethical standards of the institution at which the studies were conducted; Agriculture Animal Care and Use Committee (Study #2017-015A, Texas A&M AgriLife Research). We thank the following organizations for permitting our research: National Park Service | Wind Cave National Park (permit #2017-SCI-0007); United States Fish and Wildlife Service | National Bison Range (permit #RR005-17); South Dakota Department of Game, Fish, and Parks | Custer State Park (permit #2017-302); The Nature Conservancy and Kansas State University | Konza Prairie Biological Station (permit #2017-476).

**Data sources**
Climatic data are available from the United States National Oceanic and Atmospheric Administration (NOAA) Gridded Climate Divisional Dataset (CLIMDIV; version 1.0.0) database. doi:10.7289/V5M32STR & https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.ncdc:C00005# (Vose et al. 2014). Ecoregions of North America shapefiles, including the Great Plains used in this study, are available from the United States Environmental Protection Agency: https://www.epa.gov/eco-research/ecoregions-north-america.

Methods

**Photogrammetry**
Distance measures of *Bison* for photogrammetric techniques were determined using a digital laser rangefinder [RX-1200i TBR/W (±0.46 m), Leupold & Stevens, Inc., Beaverton, Oregon, USA]. Photogrammetric calibration on each image was performed in FLIR ResearchIR Max software [version 4.40.1 64-bit; FLIR Systems, Inc., Wilsonville, Oregon, USA] using the built-in focal length (83.2 mm) and spatial calibration tool (17 μm pixel pitch). We used the upper rear leg of *Bison* as a standard target for distance measurement using the range finder, that is, we aimed for the center of the femur as our target for the distance measure. The hindquarters were chosen because of the reduced variability in distance measures in comparison with the forequarters, likely due to the increasing refraction of the laser in the dense, long hair of the forequarters (Martin, unpublished data).
Thermal conductivity
Thermal conductivity was a critical element to calculate thermal conductance and non-evaporative insulation-conductive heat transfer (hereafter, ‘sensible heat’ (McCafferty et al. 2011)). Total depth of insulation layer of *Bison* torso varies seasonally because of molt of woolly fur undercoat (Reinhardt 1985, Braaten and Williams 1996). Total torso insulation depth ($d$; m; see discussion in Supplemental Methods for torso mass composition and insulation depth estimation) averaged 0.0784 m in winter and 0.0371 m in summer. Total insulation averaged 0.6625 m$^2$°C/W (Christopherson and Young 1981). Thermal conductivity averaged 0.118 ($k$; W/m°C) and was calculated using Equation 1:

\[ k = \frac{d}{I} \]

Sensible heat
Calculating total heat flux of insulated portions of endotherms required sensible heat ($q_{sens}$; W•m$^{-2}$). Sensible heat was calculated using thermal conductivity, insulation depth, average core body temperature, and surface temperature. Core body temperature ($T_b$), measured as rectal temperature, for *Bison bison* below ambient air temperature of 0 °C averaged 38.4 °C (Christopherson et al. 1979). While the upper limit threshold for *Bison* (dark brown color) was not well established in the literature, the value likely lies between that for black colored *Bos taurus* at 30 °C and that for black colored *Bos indicus* at 35 °C (Nielsen-Kellerman 2009, National Academies of Sciences • Engineering • Medicine 2016); lighter colors such as white fur raises the upper limit threshold for both cattle species—effectively increasing heat tolerance.

Sensible heat was calculated using Equation 2:

\[ q_{sens} = \frac{k}{d} (T_b - T_s) \]

Total heat flux
Calculating total heat flux ($q_{tot}$; W•m$^{-2}$) follows Tattersall (Tattersall 2019) for $q_{conv}$ and $q_{rad}$, where $q_{rad}$ already included the difference between absorbed heat gain and radiative heat loss. We included $q_{sens}$ as a term in Equation 3 (McCafferty et al. 2011, Clarke 2017). Total heat flux ($q_{tot}$) was calculated using Equation 3:

\[ q_{tot} = (q_{rad} + q_{conv} + q_{sens}) \]

Total body surface heat loss
Total surface heat loss ($Q$; W) is the product of surface area and total heat flux. Calculating total body surface heat loss follows Clarke (Clarke 2017). Total surface heat loss is calculated using Equation 4.

\[ Q = SA \times q_{tot} \]

Composition of torso mass and insulation depth
Because we focus on the effective thermal window of *Bison* (i.e., the torso), we estimated the mass of the torso. At one location, site 4, slaughtered *Bison* between the ages of 1.5 – 2.5 y had a live body mass that averaged 384 – 438 kg, respectively. We calculated torso mass to best estimate the mass of the effective thermal window of *Bison* as a horizontal cylinder for thermogrammetry and comprised the following body part components: 1) hot hanging mass—
the untrimmed carcass missing viscera, distal podials, crania, and integument—averaged 235 – 272 kg (~61.5% of live body mass); 2) fresh skins (without crania) average approximately 45 – 56 kg (~12.3% of live body mass; M. Jacobson of North American Bison, LLC., pers. comm., 2020); and 3) viscera—including digesta—averaged 7 – 13% of live body mass (Huntington et al. 2019); generating an average torso mass to live body mass percentage of approximately 83.7%.

Total depth of insulation on the torso was the sum of subcutaneous fat, skin and fur. Total torso insulation depth (d; m) averaged 0.0784 m in winter and 0.0371 m in summer (Equation 5). Subcutaneous fat cover of the ribcage averaged 0.0221 m (Koch et al. 1995) and skin thickness averaged 0.015 m (McEwan Jenkinson and Nay 1975). Woolly hair covering the rib cage averaged 0.0413 m (Peters and Slen 1964) in the winter and ≤ 0.001 m in summer (Equation 6).

Equation 5. \( d_{\text{winter}} = 0.0221 \text{ (subcutaneous fat)} + 0.015 \text{ (skin thickness)} + 0.0413 \text{ (winter hair coat)} \)

Equation 6. \( d_{\text{summer}} = 0.0221 \text{ (subcutaneous fat)} + 0.015 \text{ (skin thickness)} + 0.001 \text{ (summer hair coat)} \)

**Instruments and databases**

We used a mobile weather station mounted on a leveled tripod-vane standing 0.25-m above ground at each site to record dry bulb temperature (°C), dew point temperature (°C), wind speed (m•s⁻¹), and temperature-humidity index (hereafter, heat index; °C) at 10 minute intervals during observations of Bison [Kestrel 5400AG Cattle Heat Stress Tracker; Nielsen-Kellerman Company, Boothwyn, PA, USA]. We used the nearest weather station to each site in the Daily Global Historical Climatology Network (GHCN; version 3.22; http://doi.org/10.7289/V5D21VHZ) from 1895 to 2018 (Menne et al. 2012) to obtain local daily measures of maximum temperature, minimum temperature, precipitation, snowfall, and snow depth. We used the NOAA Gridded Climate Divisional Dataset (nClimDiv; version 1.0.0; http://doi:10.7289/V5M32STR) database (Vose et al. 2014) to obtain annual, monthly, and regional measures of temperature (MAT), and precipitation (MAP).

**Weather and climate: measures, databases, and indices**

We directly measured daily weather on site for thermal camera calibrations and we obtained annual and seasonal measures of climate and weather from NOAA databases of seasonal and monthly weather, including dry bulb temperature, wind speed, and temperature-humidity index (hereafter, heat index). We used three spatial scales of weather observations because each one provides a slightly different measure of weather. We used latitude, mean annual temperature (MAT), and mean annual precipitation (MAP) to indicate annual climate at each site.

**Emissivity calibrations**

We performed emissivity validation for seasonal changes in Bison hair coat-skin emissivity. Indeed, seasonal hair coats affect physical measures (Russell and Tumlison 1996). Emissivity (ε) is a measure of a material’s radiating efficiency (Mason and Coleman 1967, Tattersall et al. 2009). An emissivity of 1.00 implies that the material is 100% efficient at radiating energy. An emissivity of 0.20 indicates that the material absorbs 80% and radiates 20% of incoming radiant energy. Knowledge of emissivity is critical for directly comparing surface temperatures
of materials. Emissivity values alter the measured temperature; the temperature is reliant upon accurate reports of the emissivity to give the true temperature of the object.

Following methods in FLIR Systems (2017), we applied 3M Scotch brand–88 black vinyl electrical tape to seasonal variants of both a hand-reared living Bison and hair-on Bison robes and allowed for all materials to thermally equilibrate. We targeted the pelvic-iliac anatomical position of both the living animal and the robe. Using FLIR ResearchIR Max (version 4.40.1; 64-bit) software, we adjusted the object of interest emissivity value until the mean temperature aligned with the mean temperature of the calibration material, here the 3M Scotch brand 88 black vinyl electrical tape, set at a known emissivity value—0.96 for the vinyl tape. Using the method described above, we confirmed the emissivity values of the textiles compared in Supplementary Table S6 below and report Bison hair, skin, and Bison-merino sheep blend wool textile emissivity values (Braaten and Williams 1996, McGregor 2012). Generally accepted emissivity values of salient materials were compared (Mason and Coleman 1967, Zhang et al. 2009, Optotherm Thermal Imaging 2018). We report emissivity for Bison hair coat (winter) and skin (summer) to be \( \varepsilon = 0.90 \) and \( \varepsilon = 0.94 \), respectively. This aligns with known values of leather (0.95–1.00), human skin (0.98–0.99). We found that the emissivity compared directly to 3M Black electric tape (0.96).

Figures

![Boxplot of winter and summer range of temperature for each locality](image)

|          | Summer Quartile Range | Winter Quartile Range |
|----------|-----------------------|-----------------------|
|          | Summer DMT (°C)       | Winter DMT (°C)       |
| 4        | 11                    | 19                    |
| 2        | 910                   | 13                    |
| 1        | 78                    | 14                    |
| 3        | 10                    | 17                    |
| 5        | 15                    | 18                    |
| 6        |                       |                       |

Fig. S1. Boxplot of winter and summer range of temperature for each locality. Solid red circle indicates daily mean temperature on the day of the summer visit, whereas solid blue triangle indicates daily mean temperature on the day of the winter visit. Numbers refer to site number.
Tables

Table S1. Summary table of body surface temperature (°C) in a multilevel mixed effects general linear model of black globe temperature (T<sub>Globe</sub>; °C) interacting with season, wet bulb globe temperature (T<sub>WBGT</sub>; °C) interacting with season, and wet bulb globe temperature. Abbreviations: β, beta coefficient; SD, standard deviation; SE standard error. Cross-validation support metrics using k(10-fold): pseudo-R<sup>2</sup> = 0.61, RMSE = 10.3, N = 779 individuals, n = 19 groups by site. Random effects (site) explained 0.26% of variance.

| Parameter | β   | SE  | z    | p            | Lower CI | Upper CI |
|-----------|-----|-----|------|--------------|----------|----------|
| x<sub>1</sub>, Season#T<sub>Globe</sub> |     |     |      |              |          |          |
| Summer    | 0.04| 0.16| 0.23 | ≤ 0.81       | -0.28    | 0.36     |
| Winter    | 0.51| 0.12| 4.26 | < 0.001      | 0.28     | 0.75     |
| x<sub>2</sub>, Season#T<sub>WBGT</sub> |     |     |      |              |          |          |
| Winter    | -0.80| 0.29| -2.75| ≤ 0.006      | -1.38    | -0.23    |
| x<sub>3</sub>, T<sub>WBGT</sub> | 1.07| 0.25| 4.31 | < 0.001      | 0.59     | 1.56     |
| β<sub>0</sub>, intercept constant | 10.47| 1.45| 7.20 | < 0.001      | 7.62     | 13.32    |
| ε, || Site: | 3.24| 0.65| ---  | ---          | 2.19     | 4.80     |
| SD of whole model | 9.71| 0.25| ---  | ---          | 9.23     | 10.21    |

Table S2. Summary table of ordinary least squares regressions of total body surface heat loss (Q; W) over estimated body mass (BM<sub>E</sub>; kg) and log of absolute value of body surface heat loss (log<sub>10</sub>Q; log<sub>10</sub>-|W|) over log of estimated body mass (log<sub>10</sub>BM<sub>E</sub>; log<sub>10</sub>-kg). Abbreviations: β, beta coefficient; SE standard error. W: Adj. R<sup>2</sup> = 0.31, RMSE = 79.1, N = 694 individuals; log|-|W|: Adj. R<sup>2</sup> = 0.36, RMSE = 0.13, N = 694 individuals.

| Parameter | β   | SE  | z    | p            | Lower CI | Upper CI |
|-----------|-----|-----|------|--------------|----------|----------|
| W         |     |     |      |              |          |          |
| x<sub>1</sub>, BM<sub>E</sub> | -0.52| 0.03| -17.7| < 0.001      | -0.57    | -0.46    |
| β<sub>0</sub>, intercept constant | -96.2| 10.2| -9.4 | < 0.001      | -116.3   | -76.2    |
| Log<sub>10</sub>-||W| |     |     |      |              |          |          |
| x<sub>1</sub>, log<sub>10</sub>BM<sub>E</sub> | 0.63| 0.03| 19.68| < 0.001      | 0.57     | 0.70     |
| β<sub>0</sub>, intercept constant | 0.82| 0.08| 10.29| < 0.001      | 0.66     | 0.98     |

Table S3. Summary table of total body surface heat loss (W) in an ordinary least squares model of growth rate (kg•y<sup>-1</sup>). Abbreviations: β, beta coefficient; SD, standard deviation; SE standard error. W: Adj-R<sup>2</sup> = 0.28, RMSE = 58.6, n = 16 groups by site.

| Parameter | β   | SE  | z    | p            | Lower CI | Upper CI |
|-----------|-----|-----|------|--------------|----------|----------|
| W         |     |     |      |              |          |          |
| x<sub>1</sub>, Growth rate (kg•y<sup>-1</sup>) | 1.57| 0.60| 2.6  | ≤ 0.021      | 0.27     | 2.86     |
| β<sub>0</sub>, intercept constant | -404.6| 48.6| -8.3 | < 0.001      | -509.0   | -300.3   |
Table S4. Summary table of heat flux (W•m⁻²) in a multilevel mixed effects general linear model of latitude interacting with season and site as a random effect. Abbreviations: β, beta coefficient; SD, standard deviation; SE standard error. Cross-validation support metrics using k₁₀-fold: pseudo-R² = 0.12, RMSE = 64.6, N = 343 individuals, n = 19 groups by site. Random effects (site) explained 0.61% of variance.

| Parameter                      | β  | SE   | z     | p      | Lower CI | Upper CI |
|-------------------------------|----|------|-------|--------|----------|----------|
| x₁, Latitude#Season           |    |      |       |        |          |          |
| Latitude_Summer               | 3.08 | 1.66 | -1.86 | ≤ 0.063 | -0.17 | -6.32    |
| Latitude_Winter               | 3.85 | 1.64 | 2.34  | ≤ 0.019 | .63   | 7.07     |
| β₀, intercept constant        | -423.55 | 67.47 | 6.28  | < 0.001 | -555.78 | -291.32 |
| ε, || Site:                    | 35.25 | 7.25 | ---   | ---    | 23.56   | 52.74    |
| SD of whole model             | 61.17 | 2.39 | ---   | ---    | 56.66   | 66.03    |

Table S5. Parameters of bison body size, body and eye temperature, and reflectance of hair and bare skin.

| Parameter                      | Abbreviation | Unit | Calculation or parameters used | Notes and references                                                                 |
|-------------------------------|--------------|------|-------------------------------|--------------------------------------------------------------------------------------|
| Surface temperature           | Tₛ           | °C   |                               | Remotely measured with FLIR T1030sc.                                                   |
| Estimated height              | Hₑ           | m    | \( \frac{d(o \times s)}{f \times i} \) | Where, \( d \) is measured distance from camera to object (m) obtained by a laser rangefinder; \( o \) is relative digital length of the object of interest in the photograph (pixels); \( s \) is sensor height of the camera (mm); \( f \) is focal length of the lens (mm); \( i \) is total picture height (pixels); and \( H \) is height of the animal (Martin and Barboza 2020). |
| Body surface area             | B            | m²   |                               | Remotely measured.                                                                     |
| Bison haircoat reflectance    | ρ₀           | 0–1, | estimated to be 0.37          | Average of: 0.04–0.05 for black cattle (Holstein (Bos taurus) and Brangus (B. taurus × B. indicus), respectively), 0.44–0.58 for red coat cattle (Holstein and Simmental (Bos taurus), respectively), and 0.37 for marsh deer (Blastocerus dichotomus). Between the wavelength range of 300–850 nm (da Silva et al. 2003); table 1. |
| Bison bare skin reflectance   | ρ₁           | 0–1, | estimated to be 0.23          | Average of: 0.06–0.07 for black cattle (Holstein (Bos taurus) and Brangus (B. taurus × B. indicus), respectively), 0.23 for black water buffalo (Bubalus bubalis; who are relatively hairless), 0.28–0.44 for red coat cattle (Simmental and Holstein (Bos taurus), respectively), and 0.31 for marsh deer (Blastocerus dichotomus). Between
**Table 1. Standard reflected temperature**

| Parameter                | Symbol | Unit | Value       | Notes                                                                 |
|--------------------------|--------|------|-------------|----------------------------------------------------------------------|
| Standard reflected       |        | °C   | Summer = 20 | the wavelength range of 300–850 nm (da Silva et al. 2003); table 2. |
| temperature             |        |      | Winter = -20|                                                                      |
| Emissivity               | ε      | 0–1  | Summer bare skin is estimated to be 0.94 whereas, winter haircoat is estimated to be 0.90 using the emissivity calibration feature in FLIR ResearchIR Max software. Following emissivity calibration protocols (FLIR Systems 2017), see SI Table S6 below. |
| Shape of object          | S      |      | Sphere,     | Horizontal cylinder was chosen because height (Hₑ) is the characteristic measure of *Bison* representing the radius of the cylinder and height into the air column (Tattersall 2019). |
|                          |        |      | hecylinder, |                                                                      |
|                          |        |      | vcyllinder, |                                                                      |
|                          |        |      | hplate,     |                                                                      |
|                          |        |      | vplate      |                                                                      |
| Dry bulb temperature     | T<sub>a</sub> | °C   | ---         |                                                                      |
| Wind speed               | V      | m \(\cdot\) s<sup>-1</sup> | ---         |                                                                      |
| Dew point temperature    | DP     | °C   | ---         |                                                                      |
| Relative humidity        | RH     | 0–1, | ---         | Recorded as percent and converted to fractional.                   |
|                         |        | fractional |          | Used in place of effective temperature (Tₑ) (Bernard et al. 1994, Liljegren et al. 2008). |
| Wet bulb globe temperature | WBGT | °C   | ---         |                                                                      |
| Daily maximum temperature | T<sub>max</sub> | °C   | max(T<sub>daily</sub>) |                                                                      |
| Daily minimum temperature | T<sub>min</sub> | °C   | min(T<sub>daily</sub> (day+1)) | T<sub>min</sub> is often reported as the low temperature preceding to T<sub>max</sub>, we have shifted the T<sub>min</sub> to be the succeeding daily low temperature because it is more physiological relevant for dumping accumulated heat from the preceding heat stress (Nairn and Fawcett 2014). |
| Daily mean temperature   | DMT    | °C   | mean(T<sub>max</sub> + T<sub>min</sub>) | ---                                                                 |

---
Table S6. Emissivity ($\varepsilon$) of selected materials used in this study.

| Material                                      | Emissivity ($\varepsilon$) | Ref.                        |
|-----------------------------------------------|----------------------------|-----------------------------|
| *Bison* bare skin (summer molt)               | 0.94                       | This study                  |
| *Bison* hair (winter woolly fur undercoat)    | 0.90                       | This study                  |
| 3M Scotch brand–88 black vinyl electrical tape* | 0.96                       | (FLIR Systems 2017)         |
| Human skin                                    | 0.98–0.99                  | (Optotherm Thermal Imaging 2018, ThermoWorks 2019) |
| Leather                                       | 0.95–1.00                  | (Optotherm Thermal Imaging 2018, ThermoWorks 2019) |

* Recommended by FLIR to determine emissivity because this material is consistent in both the short wavelength (3-5 $\mu$m) and long wavelength (8-12 $\mu$m) regions.
Literature Cited in Appendix S1

Bernard, T. E., F. N. Dukes-Dobos, and J. D. Ramsey. 1994. Evaluation and control of hot working environments: part II - the scientific basis (knowledge base) for the guide. International Journal of Industrial Ergonomics 14:129–138.

Braaten, A., and R. Williams. 1996. Bison wool fiber characteristics. https://www.ag.ndsu.edu/archive/carringt/bison/wool_fiber.htm.

Christopherson, R. J., R. J. Hudson, and M. K. Christoffersen. 1979. Seasonal energy expenditures and thermoregulatory responses of bison and cattle. Canadian Journal of Animal Science 59:611–617.

Christopherson, R. J., and B. A. Young. 1981. Heat flow between large terrestrial animals and the cold environment. The Canadian Journal of Chemical Engineering 59:181–188.

Clarke, A. 2017. Principles of Thermal Ecology: Temperature, Energy and Life. Oxford University Press, New York, NY.

FLIR Systems. 2017. Use low-cost materials to increase target emissivity. https://www.flir.com/discover/rd-science/use-low-cost-materials-to-increase-target-emissivity/.

Huntington, G., M. Woodbury, and V. Anderson. 2019. Invited Review: Growth, voluntary intake, and digestion and metabolism of North American bison. Applied Animal Science 35:146–160.

Koch, R. M., H. G. Jung, J. D. Crouse, V. H. Varel, and L. V. Cundiff. 1995. Growth, digestive capability, carcass, and meat characteristics of Bison bison, Bos taurus, and Bos x Bison. Journal of animal science 73:1271–1281.

Liljegren, J. C., R. A. Carhart, P. Lawday, S. Tschopp, and R. Sharp. 2008. Modeling the Wet Bulb Globe Temperature Using Standard Meteorological Measurements. Journal of Occupational and Environmental Hygiene 5:645–655.

Martin, J. M., and P. S. Barboza. 2020. Decadal heat and drought drive body size of North American bison (Bison bison) along the Great Plains. Ecology and Evolution 10:336–349.

Mason, M. T., and I. Coleman. 1967. Study of the surface emissivity of textile fabrics and materials in the 1 to 15 μm range. Page Institute for Applied Technology, National Bureau of Standards, U.S. Department of Commerce. Cambridge, Massachusetts.

McCafferty, D. J. J., C. Gilbert, W. Paterson, P. P. Pomeroy, D. Thompson, J. I. I. Currie, and A. Ancel. 2011. Estimating metabolic heat loss in birds and mammals by combining infrared thermography with biophysical modelling. Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology 158:337–345.

McEwan Jenkinson, D., and T. Nay. 1975. The sweat glands and hair follicles of different species of Bovidae. Australian Journal of Biological Sciences 28:55–68.

McGregor, B. A. 2012. Production, properties and processing of American bison (Bison bison) wool grown in southern Australia. Animal Production Science 52:431–435.

Menne, M. J., I. Durre, R. S. Vose, B. E. Gleason, and T. G. Houston. 2012. An overview of the Global Historical Climatology Network-Daily database. Journal of Atmospheric and Oceanic Technology 29:897–910.

Nairn, J. R., and R. J. B. Fawcett. 2014. The excess heat factor: a metric for heatwave intensity and its use in classifying heatwave severity. International Journal of Environmental Research and Public Health 12:227–253.

National Academies of Sciences • Engineering • Medicine. 2016. Nutrient requirements of beef
cattle. Page (Committee on Nutrient Requirements of Beef Cattle / Board on Agriculture and Natural Resources / Division on Earth and Life Studies, Ed.). 8th edition. The National Academies Press, Washington, DC.

Nielsen-Kellerman. 2009. Kestrel: 5400AG cattle heat stress tracker. Boothwyn, Pennsylvania.

Optotherm Thermal Imaging. 2018. Emissivity in the infrared. http://www.optotherm.com/emiss-table.htm.

Peters, H., and S. Slen. 1964. Hair coat characteristics of bison, domestic× bison hybrids, cattalo, and certain domestic breeds of beef cattle. Canadian Journal of Animal Science 44:48–57.

Reinhardt, V. 1985. Quantitative analysis of wallowing in a confined bison herd. Acta Theriologica 30:149–156.

Russell, J. E., and R. Tumlison. 1996. Comparison of microstructure of white winter fur and brown summer fur of some Arctic mammals. Acta Zoologica 77:279–282.

da Silva, R. G., N. La Scala Jr., and H. Tonhati. 2003. Radiative properties of the skin and hair coat of cattle and other animals. Transactions of the ASAE 46:913–918.

Tattersall, G. J. 2019. Thermimage: thermal image analysis. CRAN.

Tattersall, G. J., D. V. Andrade, and A. S. Abe. 2009. Heat exchange from the toucan bill reveals a controllable vascular thermal radiator. Science 325:468–470.

ThermoWorks. 2019. Emissivity Table. https://www.thermoworks.com/emissivity_table.

Vose, R. S., S. Applequist, M. Squires, I. Durre, M. J. Menne, J. Williams, Claude N., C. Fenimore, K. Gleason, and D. Arndt. 2014. NOAA’s Gridded Climate Divisional dataset (CLIMDIV).

Zhang, H., T. L. Hu, and J. C. Zhang. 2009. Surface emissivity of fabric in the 8-14 μm waveband. Journal of the Textile Institute 100:90–94.