



Winter range use by cattle : microclimate and diet selection
by John Michael Beaver

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Range Science

Montana State University

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Abstract:

In northern climates, winter conditions can cause animals to lose weight and body condition. Our first objective was to compare winter range use by young cattle, inexperienced with winter range, with old cattle experienced with winter range. Our second objective was to determine if simple micrometeorological measurements could accurately model standard operative temperature (Tes) in mule deer and cattle in winter. Our final objective was to determine if cattle select higher quality diets than that present in two dormant native bunchgrasses.

With Objective One, we alternated 3 year old cows weekly with 7-8 year old cows on the same 150 ha pasture for approximately two months over two winters. We measured standing crop at different locations within the pasture, and at cattle locations. We calculated standard operative temperature (Tes) based on ambient and blackglobe temperatures and windspeed, and cattle resistance to heat loss. We calculated Tes at group locations, and at 12 locations in the pasture to assess available thermal environments.

Three year old cattle used unprotected areas more often than 7-8 year old cattle. Three year old cattle were in areas where Tes were below their lower critical temperature more often than 7-8 year old cattle. Three year old cattle did not graze in areas with higher standing crop than what was initially available although 7-8 year old cattle did. Microclimates were more important than forage in predicting 7-8 year old cattle use of the pasture.

For Objective Two, we calculated Tes for mule deer and cattle in winter. We regressed Tes with blackglobe and ambient temperature, and windspeed. We applied our mule deer regression model to an independent data set with different weather conditions. Our mule deer and cattle regression models represented Tes well for both species (adj. $R^2 = .96$ and $.97$, respectively). Our mule deer regression model also matched the independent data set well.

For Objective Three, we randomly located and clipped three plants of Idaho fescue (*Festuca idahoensis*) and bluebunch wheatgrass (*Agropyron spicatum*) at 12 transects within a 324 ha pasture. We clipped three times during the 1993-94 winter, and once during the 1994-95 winter due to low variability in the first winter. We also evacuated the rumens of six cattle three times during the winter, allowed them to graze for 45 min to 1 h, and collected rumen samples. There was less green material in the rumen samples than in the clipped samples on all but one occasion indicating that during these two winters, cattle were unable to select a higher quality diet than that available.

Winter range in northern climates challenges an animal's ability to maintain homeostasis, and obtain adequate nutrition. Seven-eight year old cattle are apparently more adept at avoiding cold extremes than are 3 year old cattle. When there is little green material available both age groups are probably unable to select higher quality diets than that usually available during winter.

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APPROVAL

of a thesis submitted by

John Michael Beaver

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

16 July 1995
Date

B. E. OI
Chairperson, Graduate Committee

Approved for the Major Department

July 10, 1995
Date

J. Faberson
Head, Major Department

Approved for the College of Graduate Studies

8/19/95
Date

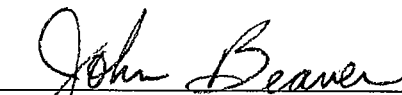
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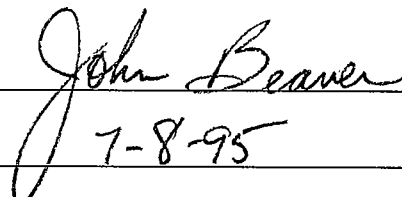
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ABSTRACT

In northern climates, winter conditions can cause animals to lose weight and body condition. Our first objective was to compare winter range use by young cattle, inexperienced with winter range, with old cattle experienced with winter range. Our second objective was to determine if simple micrometeorological measurements could accurately model standard operative temperature (T_{es}) in mule deer and cattle in winter. Our final objective was to determine if cattle select higher quality diets than that present in two dormant native bunchgrasses.

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Three year old cattle used unprotected areas more often than 7-8 year old cattle. Three year old cattle were in areas where T_{es} were below their lower critical temperature more often than 7-8 year old cattle. Three year old cattle did not graze in areas with higher standing crop than what was initially available although 7-8 year old cattle did. Microclimates were more important than forage in predicting 7-8 year old cattle use of the pasture.

For Objective Two, we calculated T_{es} for mule deer and cattle in winter. We regressed T_{es} with blackglobe and ambient temperature, and windspeed. We applied our mule deer regression model to an independent data set with different weather conditions. Our mule deer and cattle regression models represented T_{es} well for both species (adj. R^2 = .96 and .97, respectively). Our mule deer regression model also matched the independent data set well.

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Winter range in northern climates challenges an animal's ability to maintain homeostasis, and obtain adequate nutrition. Seven-eight year old cattle are apparently more adept at avoiding cold extremes than are 3 year old cattle. When there is little green material available both age groups are probably unable to select higher quality diets than that usually available during winter.

CHAPTER 1

INTRODUCTION

In northern climates, thermal conditions and low forage nutritional quality can increase weight loss in animals and decrease reproductive performance. In winter animals often decrease their exposure to wind or increase their exposure to long and short wave radiation (Senft and Rittenhouse, 1985; Schwab and Pitt, 1991; Sakurai and Dohi, 1992). This is important where environmental conditions may be below the animal's thermoneutral zone. However, animals must balance this thermoregulatory behavior so that it does not conflict with other behaviors such as obtaining food (Ingram and Dauncy, 1985). Presumably, animals thermoregulate by alternating behaviors that require energy with those that conserve energy. The thermal and forage characteristics of an area may influence how often, and in what way an animal uses that area.

The ability to match behaviors to thermal and forage resources may be learned or innate. Several studies show that young, inexperienced animals improve their foraging skills and social abilities by associating with older, experienced animals (Provenza and Balph, 1987; Thorhallsdottir et al., 1990; Green, 1992; Olson et al., 1992). Habitat selection may also be learned (Hunter and Milner, 1963; Wecker, 1963). In Chapter 2, we compared winter range use by 7-8 year old cattle experienced with winter range, with 3 year old cattle inexperienced with winter range.

The thermal environment which an animal experiences is not accurately described

by ambient temperature or some other weather measurement alone. Operative temperature and the related standard operative temperature are often used as biophysical indices of an animal's thermal environment (Bakken, 1980; Parker and Robbins, 1984; Vispo and Bakken, 1993). Operative and standard operative temperature incorporate variables such as ambient temperature, windspeed, and short and long-wave radiation with species specific variables such as resistance to heat flow. Thus they more accurately represent the thermal environment that an animal experiences.

Measuring standard operative temperature in the field can be difficult. Measurements usually require expensive equipment which is not easily mobile, or life-like copper mounts of animals (Crawford et al., 1983; Bakken et al., 1985; Bakken, 1992). Standard operative temperature would be more useful to ecologists and biologists if mathematical models could relate it to more easily obtained microclimate measurements. In Chapter 3, we determined if regression equations could incorporate simple micrometeorological data to model standard operative temperature for two large endotherms, mule deer and cattle.

In addition to stressful thermal environments, animals can be stressed by poor forage quality in winter. Cattle diet selection in winter is inhibited by overall poor forage quality (Stuth, 1990). The amount of green material in a forage sample should be an index of its nutritional quality. Green herbage of Idaho fescue (*Festuca idahoensis*) and bluebunch wheatgrass (*Agropyron spicatum*) is higher quality forage at all times of the year than dead forage (Houseal and Olson, accepted). Thus, cattle diet selection can be estimated by comparing the amount of green forage in rumen samples with that available

in the pasture or landscape (Launchbaugh et al., 1990). In Chapter 4, we determined if cattle select diets of higher quality than is generally available on native winter range by comparing the amount of green material in rumen samples with randomly clipped native bunchgrasses.

CHAPTER 2

WINTER RANGE USE BY DIFFERENT AGED CATTLE
IN SOUTHWESTERN MONTANAIntroduction

In northern climates, winter conditions can severely stress animals. Because cold stress requires an animal to raise its regulatory heat production to maintain a constant body temperature (Christopherson, 1985), there is less energy available for growth and feeding efficiency (Webster et al., 1970). Cattle and other endotherms use a variety of physiological and behavioral mechanisms to avoid cold stress (Parker and Robbins, 1985). In winter animals often decrease their exposure to wind or increase their exposure to long and short wave radiation (Senft and Rittenhouse, 1985; Schwab and Pitt, 1991; Sakurai and Dohi, 1992). This is important in an environment where ambient conditions may be below the animal's thermoneutral zone.

Animals are capable of seeking out microclimates to reduce their exposure. However, they must balance this behavior so that it does not conflict with other behaviors such as obtaining food (Ingram and Dauncy, 1985). Presumably, animals thermoregulate by alternating behaviors that require energy with those that conserve energy. In a landscape that consists of a range of available microclimates and forage resources, animals may be able to graze, an energetically expensive activity (Osuji, 1974; Malechek and Smith, 1976), in moderate microclimates. Thus, thermal environments and forage

resources such as standing crop and nutritional quality interact to determine an animal's location.

The ability to balance grazing and resting behavior with thermal and forage resources may be learned or innate. Several studies show that young, inexperienced animals improve their foraging skills and social abilities by associating with older, experienced animals (Provenza and Balph, 1987; Thorhallsdottir et al., 1990; Green, 1992; Olson et al., 1992). Habitat selection may also be learned (Hunter and Milner, 1963; Wecker, 1963). Learning to use resources efficiently may lessen weight loss or loss of condition of animals in winter. The objective of our study was to determine if older cattle, experienced with winter grazing use winter range resources differently than younger cattle, inexperienced with winter grazing.

Methods

Study Site and Animals

The study site is a 150 hectare pasture on the Montana Agricultural Experiment Station Red Bluff Research Ranch (latitude 45° 35'N, longitude 111° 39'W) near Norris, Montana. The pasture has sandy and silty range sites common to southwestern Montana. Topography is varied with three large draws, and several smaller draws within the pasture. Slopes are predominately southwest facing, and usually snowfree because of persistent winds and high solar radiation during most of the winter. Elevations range from approximately 1520 - 1770 m. Three small springs provide water. The dominant

habitat type is *Festuca idahoensis*/*Agropyron spicatum* with a *Rhus trilobata*/*Festuca idahoensis* habitat type occurring on the southwest slopes of major draws (Mueggler and Stewart, 1980). Rocky Mountain juniper (*Juniperus scopulorum*) and limber pine (*Pinus flexilis*) are scattered on the slopes throughout the pasture, and chokecherry (*Prunus virginianus*) occurs along the springs in the bottoms of draws. Along with topographical variation, this larger vegetation provides a range of microclimates. Each year prior to our study, the pasture was lightly grazed in late fall by cattle. This reduced standing crop slightly around water, salt, and supplement areas.

We alternated two groups of Angus x Hereford cattle, one experienced with winter range (7-8 year olds), and one inexperienced with winter range (3 year olds) every other week on the pasture. During Winter 1 (29 Dec. 1993 to 4 Feb. 1994), there were ten cattle per group. During Winter 2 (18 Dec. 1994 to 17 Feb. 1995), ten cattle were in the 7-8 year old group and nine were in the 3 year old group. In Winter 1, we observed each group for three weeks. In Winter 2, we extended the observation period to four weeks per group to encompass a wider variety of weather extremes.

During both winters we recorded grazing, resting, and traveling time (min) for the majority of each group from 0800 to 1600 h. In Winter 2, we individually weighed and measured backfat on all cattle immediately before and after the study. The mean initial weight and backfat of 7-8 year old cattle was 625 ± 19.5 kg (SE) and $.38 \pm .08$ cm (SE) respectively. The mean initial weight and backfat of 3 year old cattle was 544 ± 15.5 kg (SE) and $.52 \pm .10$ cm (SE) respectively. We compared weight and backfat loss between the two groups using initial body weight and backfat as covariates. In a small herd

animal behavior is not necessarily independent. Therefore, changes in weight and backfat should be considered subsamples and not replicates. Thus, these results cannot be inferred to other cattle grazing winter pasture (Wester, 1992).

The cattle were not supplemented or fed during the observation period of either winter. During Winter 1, only cattle in the 7-8 year old group were pregnant. During Winter 2, both groups of cattle were pregnant. When a group was not on the study pasture, it was in an adjoining pasture of similar vegetation and soils, although the topography was less varied. Interaction between the two groups was infrequent and short.

Environmental Measurements

To assess how 7-8 year old and 3 year old cattle use certain microclimates relative to the range of microclimates available, we established 3 transects of increasing elevation on the pasture with four weather stations per transect. Four landscape positions were represented by the twelve stations. Three were along an exposed ridge, three were at midslope of the ridge, three were at locations within a draw, and three were along an open bench. We measured blackglobe (T_g) and ambient temperatures (T_a), and windspeed ($m s^{-1}$) at backbone height to a cow (1.3 m, Yousef, 1989) at each cattle groups' location. We clipped three .25 m² frames to determine standing crop in the immediate vicinity of each group. We recorded whether the majority of the group was grazing or resting. We also visually classified the majority of the groups' location as unprotected, moderately protected, or protected from wind exposure by large vegetation or topography. We then

immediately measured the same weather variables at the twelve weather stations to compare weather conditions at the group location with conditions available in the pasture. Total time between all measurements was 30 to 40 min. We recorded the above measurements at 0800, 1200, and 1600 hr on days 1, 3, and 5 of each week (n=27 Winter 1, n=36 Winter 2).

Our blackglobe thermometer was a 10.2 cm copper sphere painted matte black (Bond and Kelly, 1955) that has a short and long wave absorptivity similar to most animal and natural surfaces (.89 and .95 respectively; Campbell, 1977; Walsberg, 1992). A mercury thermometer was inserted through a rubber stopper into the center of the globe. The ambient thermometer consisted of a mercury thermometer surrounded by an aluminum shield to shade the thermally sensitive end. We averaged windspeeds over ten seconds at the cattle locations and weather stations with a hand held digital anemometer.

Before turning cattle onto the pasture, we clipped .25 m² frames in protected, moderately protected, and unprotected areas of the pasture. We sampled enough plots per area to be within 20% of the mean with 90% confidence (n=90 Winter 1; n=71 Winter 2). In Winter 1, plots were interspersed across the pasture within protection classes (Hurlbert, 1984). In Winter 2, plots were randomly chosen within protection classes. We used planned linear contrasts to determine if standing crop in protection classes selected by cattle was different from what was available in the protection classes. In the same manner we compared standing crop among protection classes selected by cattle. *P*-values < 0.10 are discussed. Since we considered the pasture the experimental unit this study is not replicated. Thus we did not make statistical comparisons between winters to avoid

temporal pseudoreplication (Hurlbert, 1984).

Forage sampled before our study cattle used the pasture, and that sampled at cattle locations during the study, were dried in a forced air oven at 37°C for 5 to 7 days and weighed. In Winter 2, we composited samples taken at cattle locations by collection time and day, ground them through a 1 mm Wiley mill, and analyzed them for crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF). Forage data are expressed on a dry matter basis.

Thermal Index

Although ambient temperature has often been used to represent the thermal environment experienced by an animal, it does not incorporate all of the components that characterize the thermal environment that an animal experiences. Standard operative temperature, T_{es} (Bakken, 1980; 1981) is a more appropriate biophysical index because it incorporates the animal's resistance to heat loss, its body temperature, long and short wave radiation, and windspeed. Standard operative temperature and operative temperature T_e (Winslow et al., 1937; Campbell, 1977) have often been used to express the thermal environment experienced by large endotherms (Parker and Gillingham, 1990; Merrill, 1991; Schwab and Pitt, 1991; Demarchi and Bunnell, 1993). Standard operative temperature is expressed as:

$$T_{es} = T_b - [(r_{bs} + r_{es}) / (r_b + r_e)] \cdot (T_b - T_e) \quad (1)$$

where T_b is body temperature ($^{\circ}\text{C}$), r_b is the thermal resistance of skin and insulation (s m^{-1}), r_e is the thermal resistance between outer surface and environment (s m^{-1}), and r_{bs} and r_{es} are the values of r_b and r_e in the standard environment with windspeed $< 1 \text{ m s}^{-1}$ (Bakken, 1981).

To calculate T_{es} generally requires either sophisticated equipment such as a pyranometer and a net radiometer, or a realistic copper model of the animal being measured (Merrill, 1991; Walsberg, 1992; Bakken, 1992). Because this equipment is difficult to transport, and because we did not have a copper model of a cow, we developed a mathematical relationship between T_{es} , and windspeed, and blackglobe and ambient temperature (adjusted $r^2 = .94$). We substituted this equation for T_{es} (Chapter 3). We used T_b for beef cattle of 38.6°C (Christopherson et al., 1979), and resistance ratios appropriate for cattle as estimated by Webster (1970). We estimated T_{es} at the group location and compared that with mean T_{es} estimated at the exposed ridge weather stations, and with mean T_{es} estimated at the protected draw weather stations. We also compared the T_{es} estimated at the above locations with the assumed lower critical temperatures (LCT) of -23°C for pregnant cattle, and -13°C for the non-pregnant cattle in Winter 1 (Webster, 1970). In Winter 2, both groups were composed of pregnant animals, and thus their LCT was assumed to be -23°C . An animal's LCT is the temperature at which it must raise its regulatory heat production to maintain a constant body temperature. Comparing T_{es} at animal and transect locations to the LCT is an indirect measure of actual or possible cold stress in various environments.

GIS and Logistic Regression Analysis

Thermal and forage resources are distributed unevenly across the pasture. Therefore we created a geographic information system GIS (Arc/Info, 1992) overlay of topography and larger vegetation, such as trees and shrubs, to map areas which were protected, moderately protected, and unprotected from wind. Arc/Info classified the percentage of the pasture in each category. We then compared the relative abundance of protection classes to their relative use by each group.

We used wind direction as the main determinate to distinguish between protection classes. The prevailing wind direction in the pasture is from 160° to 230°, therefore, we programmed the model to label areas with aspects between 340° and 50° in a draw with large vegetation as "protected". "Moderately protected" areas were defined as areas either with large vegetation outside of a draw, or in a draw without large vegetation between aspects 340° and 50°. We defined "unprotected" areas as the remaining pasture. We used Ivlev's electivity index (Ivlev, 1961; Yeo et al., 1993) to determine if cattle were in protection classes more or less than the relative abundance of those classes. The index is expressed as:

$$EI = (\text{Observed} - \text{Available}) / (\text{Observed} + \text{Available}) \quad (2)$$

where EI = electivity index, Observed = the observations in a particular protection class, and Available = the percent of the pasture within a particular protection class. Positive

numbers from 0 to 1 express preference, and negative numbers from 0 to -1 express avoidance. The closer the number is to 1 or -1, the stronger the preference or avoidance, respectively.

We used stepwise logistic regression with protection class as the dependent variable within experience group to determine which weather and forage features influenced the probability of cattle selection of microsites (SAS, 1988). We included T_{es} at cattle and weather stations, and slope, aspect, forage quantity (kg ha^{-1}), and quality (CP , ADF , NDF) the second year, at cattle locations as independent variables. Variables which were not significant in the model are not discussed. By incorporating variables at the cattle and weather station locations we could determine how cattle select microclimates relative to prevailing forage and microclimate resources. We used the log likelihood ratio to determine if the model was significant, and the Wald chi-square statistic with its associated P -value as indicators of the relative significance of independent variables (Trexler and Travis, 1993). They recommend using logistic regression for regression analysis of categorical data.

Results

Animals

In Winter 1, 7-8 year old cattle traveled less per day than 3 year old cattle although total minutes grazing and resting were similar (22 min/day vs. 76 min/day). During the morning, noon, and afternoon weather measurements, 7-8 year old cattle

rested more often in either protected or moderately protected sites, and grazed more often in unprotected sites. Three year old cattle use patterns were generally similar to 7-8 year old cattle use patterns (Table 1).

In Winter 2, 7-8 year old and 3 year old cattle spent similar amounts of time grazing, resting, and traveling. As in Winter 1, 3 year old cattle use patterns were generally similar to 7-8 year old cattle use patterns (Table 1).

Table 1. Percent time grazing (G) and resting (R) in protected (P), moderately protected (MP), and unprotected (UP) areas by 7-8 year old and 3 year old cattle in Winter 1 and Winter 2.

		P		MP		UP	
		7-8 yr	3 yr	7-8 yr	3 yr	7-8 yr	3 yr
Winter 1	G	0	0	40	0	82	65
	R	100	100	60	100	18	35
Winter 2	G	40	50	50	63	65	50
	R	60	50	50	37	35	50

In Winter 2, 7-8 year old cattle lost 36 ± 3.4 kg (SE), and $.11 \pm .07$ cm (SE) of backfat. Three year old cattle lost 56.8 ± 5.0 kg (SE), and $.30 \pm .11$ cm (SE) of backfat. Seven-eight year old cattle lost less backfat ($P=0.06$) and weight ($P=0.0003$) than 3 year old cattle.

Environmental Measurements

In Winter 1, forage standing crop was lower in protected areas than it was in unprotected areas selected by 7-8 year old cattle ($P=0.08$). There was no relationship between forage standing crop and the selection of different protection classes by 3 year old cattle (Fig. 1a).

In Winter 2, standing crop was lower in protected ($P=0.002$) and moderately protected ($P=0.02$) areas selected by 7-8 year old cattle compared with unprotected areas selected by 7-8 year old cattle. Standing crop in unprotected areas selected by 7-8 year old cattle was also greater than that sampled in unprotected areas before the cattle entered the pasture ($P=0.001$). There was no relationship between forage standing crop and the selection of different protection classes by 3 year old cattle (Fig. 1b). Crude protein, *NDF*, and *ADF* were similar among sites in the different protection classes ($P>0.10$; Table 2).

Figure 1. Mean standing crop available in the pasture, and at 7-8 year old and 3 year old cattle locations within protected (P), moderately protected (MP), and unprotected (UP) areas during Winter 1 and 2. Error bars are standard errors.

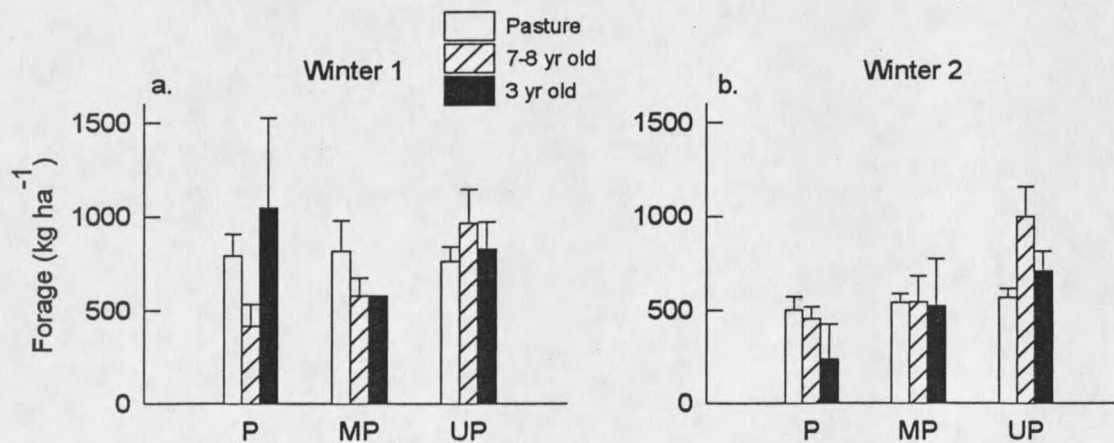
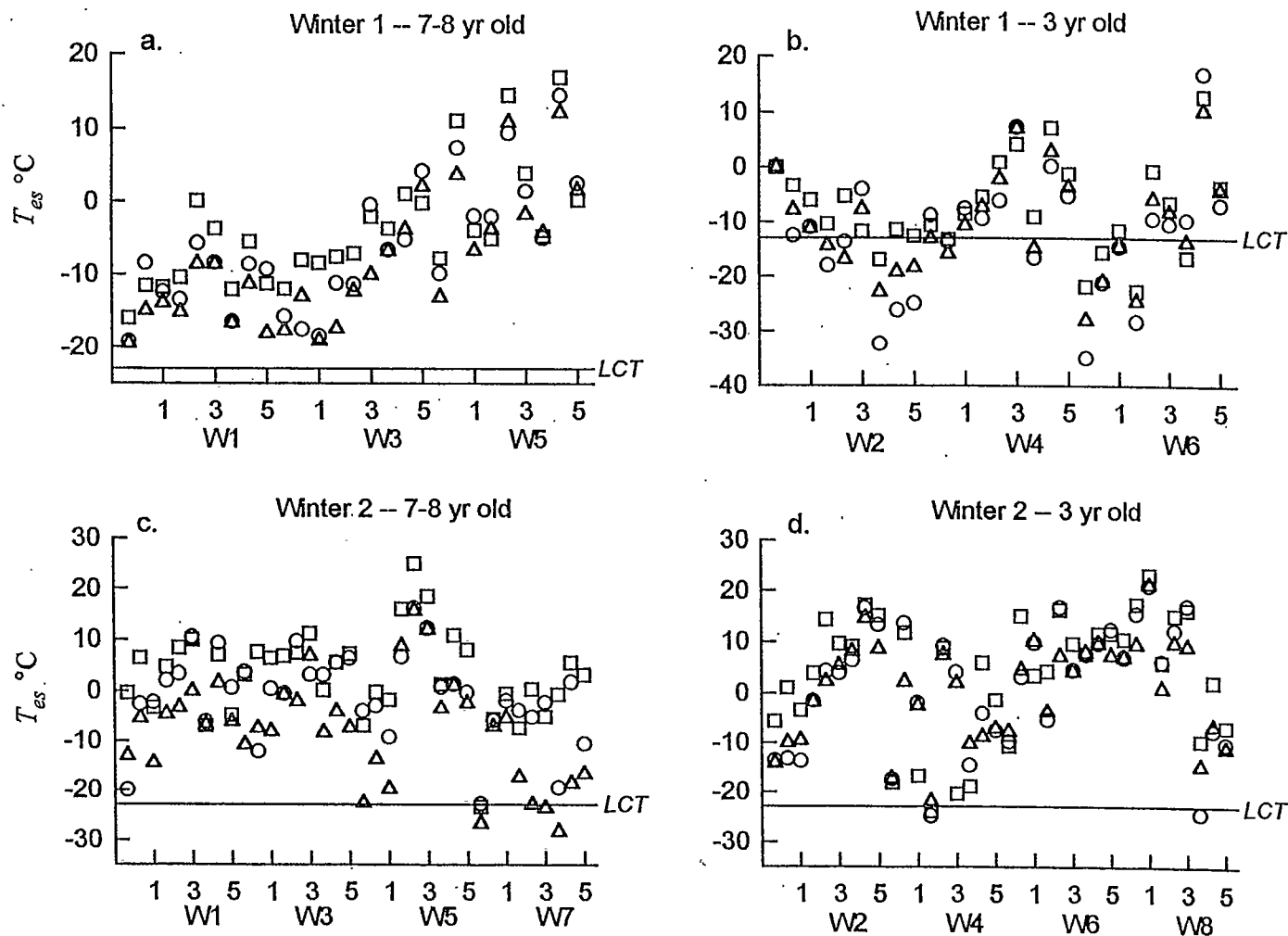


Table 2. Mean crude protein (*CP*), neutral detergent fiber (*NDF*), and acid detergent fiber (*ADF*), in protected (P), moderately protected (MP), unprotected (UP), and grazing (G) and resting (R) areas selected by 7-8 year old and 3 year old cattle in Winter 2. Standard errors are noted in parentheses.

		P	MP	UP
7-8 yr old	<i>CP</i>	5.28 (.74)	5.66 (.36)	4.75 (.16)
	<i>NDF</i>	74.59 (.65)	73.96 (.88)	75.19 (.82)
	<i>ADF</i>	42.46 (.58)	42.64 (1.0)	44.24 (.66)
3 yr old	<i>CP</i>	5.12 (1.1)	5.23 (.61)	5.25 (.18)
	<i>NDF</i>	73.82 (.14)	74.79 (1.0)	74.40 (.71)
	<i>ADF</i>	43.00 (1.0)	42.60 (.81)	42.91 (.57)

Weather was variable over both winters. In Winter 1, the mean T_{es} estimated from the ridge transects, the coldest points in the pasture, was $-10.49 \pm 2.53^{\circ}\text{C}$ (SE) when 7-8 year old cattle were observed, and $-16.11 \pm 2.96^{\circ}\text{C}$ (SE) when 3 year old cattle were observed. In Winter 2, mean T_{es} estimated from the ridge transects was $-20.42 \pm 2.86^{\circ}\text{C}$ (SE) when 7-8 year old cattle were observed, and $-6.63 \pm 2.85^{\circ}\text{C}$ (SE) when 3 year old cattle were observed. In Winter 1, 93% of T_{es} at 7-8 year old cattle locations were at or above the coldest T_{es} measured in the pasture. Three T_{es} at 7-8 year old locations were below the *LCT* of -23°C (Fig. 2a). In contrast, 54% of T_{es} at 3 year old cattle locations were above the coldest T_{es} measured in the pasture. Several T_{es} at 3 year old cattle and transect locations were below the *LCT* of -13°C (Fig. 2b).

Figure 2. Standard operative temperatures (T_{es}) at cattle = $\circ$, draw = $\square$, and ridge = $\triangle$ locations within the pasture for Winter 1 (a, b) and 2 (c, d). Days per week (W) are noted on the x-axis. For each day, microclimates were measured at 0800, 1200 and 1600 h and are depicted on figures. Note that the scale of the y-axis differs in Winter 1.



In Winter 2, 89% of T_{es} at 7-8 year old cattle locations were at or above the coldest T_{es} measured in the pasture. Several T_{es} at transects were below the LCT , although T_{es} at 7-8 year old cattle locations were never below the LCT (Fig 2c). Unlike Winter 1, 75% of T_{es} at 3 year old cattle locations were above the coldest T_{es} measured in the pasture. Standard operative temperatures at transect locations were never below the LCT of -23°C . However, two T_{es} at 3 year old cattle locations were below -23°C (Fig. 2d).

GIS and Logistic Regression Analysis

Seven-eight year old and 3 year old cattle used most parts of the pasture over both winters (Fig. 3). In Winter 1, both groups tended to prefer the protected areas in the pasture (Table 3). Seven-eight year old cattle preferred the moderately protected and avoided the unprotected areas. Three year old cattle avoided the moderately protected areas and used the unprotected area in proportion to its availability. In Winter 2, 7-8 year old cattle preferred protected and moderately protected areas and avoided the unprotected areas. Three year old cattle avoided protected areas, and used moderately and unprotected areas in proportion to their availability (Table 3).

In Winter 1, standing crop, and T_{es} at cattle and ridge locations predicted 7-8 year old cattle use of the three protection classes (Table 4). Standard operative temperature at cattle and draw locations predicted 3 year old cattle use of the three protection classes (Table 4). However, since 3 year old cattle were in unprotected areas 80% of the time, the model predicted 3 year old cattle in unprotected areas all but once.

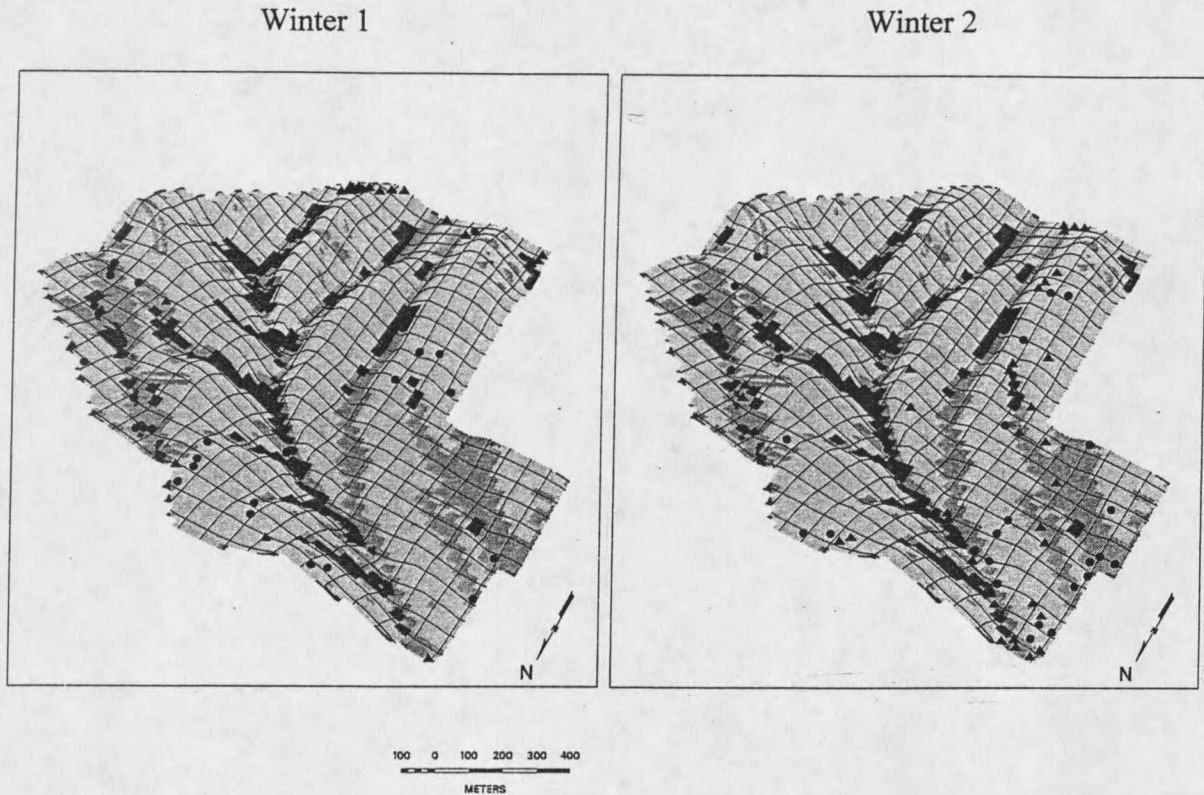


Figure 3. Seven-eight year old (●) and 3 year old (▲) cattle locations in Winter 1 and 2. Protection classes range from dark to light with protected areas the darkest, moderately protected areas lighter, and unprotected areas lightest.

In Winter 2, T_{es} at cattle, ridge, and draw locations predicted 7-8 year old cattle use of the three protection classes. Standard operative temperature and standing crop did not predict 3 year old cattle use of the three protection classes (Table 4).

Table 3. Percent of pasture and percent of observations with 7-8 year old and 3 year old cattle in protected (P), moderately protected (MP), and unprotected areas (UP) in Winter 1 and 2. The number of observations are noted in parentheses. Electivity Index (*EI*) for both groups for the three protection classes.

		P	MP	UP	<i>EI</i>		
%Pasture		9.56	20.28	70.16	P	MP	UP
Winter 1	7-8 yr	18.52 (5)	40.74 (11)	40.74 (11)	.32	.36	-.27
	3 yr	15.39 (4)	3.85 (1)	80.77 (21)	.23	-.68	.07
Winter 2	7-8 yr	27.78 (10)	33.33 (12)	38.89 (14)	.49	.24	-.29
	3 yr	5.55 (2)	22.22 (8)	72.22 (26)	-.27	.05	.01

Table 4. Significant logistic regression parameters¹ for predicting the probability that 7-8 year old or 3 year old cattle were in one of the three protection classes for Winter 1 and 2.

		Parameters	$P > \chi^2$
Winter 1	7-8 yr	standing crop	0.03
		Tes (cow location)	0.01
		Tes (ridge transect)	0.03
	3 yr	Tes (cow location)	0.05
		Tes (draw transect)	0.02
Winter 2	7-8 yr	Tes (cow location)	0.001
		Tes (draw transect)	0.001
	3 yr	none	NS

¹ The probability of being in a protection class is $P = e^y / (1 + e^y)$, where y is the estimated regression value based on significant parameters.

Discussion

Overall, 7-8 year old cattle preferred to use areas with at least some protection. Seven-eight year old cattle probably chose protected areas to avoid weather extremes, not for forage availability, because these areas had the lowest available standing crop. Resting in protected areas during cold periods should require less energy than resting in exposed areas. Metabolic rates of cattle are lower during relatively warm, still conditions than during colder, windier conditions (Christopherson, 1979).

Similar environmental variables influenced 7-8 year old cattle use of microclimates in Winter 1 and Winter 2. Also, 7-8 year old cattle preferred protection classes with similar frequency in Winter 1 and Winter 2. In contrast, different variables influenced 3 year old cattle use of microclimates in Winter 1 than in Winter 2. Furthermore, 3 year old cattle did not prefer protection classes similarly in Winter 1 as in Winter 2. Animals which are inexperienced with an area must first understand the landscape before they can use it efficiently (Stuth, 1991). Presumably use of the pasture by 3 year old cattle was more variable because they were unfamiliar with that environment.

In Winter 1, 3 year old cattle became habituated to a high point in the pasture which was often the coldest point measured. Initially this area had high standing crop ($904 \pm 140 \text{ kg ha}^{-1} \text{ SE}$), but they continued to return regularly even though standing crop

had declined by the second half of the study period (594 ± 96 kg ha⁻¹ SE). Three year old cattle were less variable during Winter 2 than during Winter 1. However, they did not match their grazing and resting behaviors to available standing crop and weather conditions as well as 7-8 year old cattle either year. Seven-eight year old cattle grazed in protected and moderately protected areas more often during cold periods. Three year old cattle continued to graze in unprotected areas even when conditions were below their *LCT*. Thus, 7-8 year old cattle probably used the pasture more efficiently than did the 3 year old cattle.

Seven-eight year old cattle may have lost less weight and backfat because they integrated their behavior with forage and thermal resources. In winter, the percentage of body fat on Angus x Hereford cattle is important in decreasing metabolic energy requirements for maintenance (Chavez et al., 1989). Although 3 year old cattle started the study with relatively more backfat than 7-8 year old cattle, they lost more possibly because of exposure to weather, less efficient behavior, and growth.

The 7-8 year old cattle were more adept at "matching" their behavior to the environment than the 3 year old cattle (Staddon, 1983; Senft et al., 1987). The concept of matching describes foraging behavior in proportion to dietary rewards. Over-matching is a disproportionately large response to a change in reward (Senft et al., 1987). Matching occurs within the context of factors such as topography, microclimate, and watering areas. These are "driving variables" that affect forage utilization but, in turn, are not affected by forage use (Senft et al., 1987). Moose select higher canopy cover for thermal benefits in winter when operative temperatures are above the temperature at which they

pant to dissipate heat. Conversely when temperatures are below that point, moose choose areas with high forage availability (Schwab and Pitt, 1991).

Similar to moose, 7-8 year old cattle matched their grazing and resting behaviors to the available forage within the context of a varying thermal environment. During Winter 2, 7-8 year old cattle may have even overmatched their grazing behavior to forage availability in protected and moderately protected areas because of colder conditions. Higher forage standing crop was available in more exposed areas, but 7-8 year old cattle often selected areas of lower standing crop with higher thermal cover.

Matching relative time allocated to an activity with its relative reward is often discussed in foraging theory (Stephens and Krebs, 1986). However, "rewards" should be considered in a broad context. Smith (1988) proposed that animals have a hierarchy of needs in the order of water balance, endothermy, caloric balance, and rest. Animals will not reflect this behavior under all circumstances. In winter, water may not be as critical. Voluntary water intake of beef cattle decreases with decreasing ambient temperature (Conrad, 1985). Furthermore, we often observed cattle eating snow which may have substituted for drinking water. Thus, the reward of water may sometimes be replaced by other rewards depending on the environment.

Maintaining endothermy by decreasing exposure may occasionally influence cattle location more than forage. Standard operative temperatures were generally more important in predicting cattle locations than standing crop or forage quality. Topographic variables can explain range use patterns of cattle on short-grass steppe better than forage variables (Senft et al., 1983). Although slope and aspect of cattle locations were not

significant in our models, it is the interaction of topography and weather which creates different microclimates. Prescott et al. (1994) hypothesized that access to microclimates may explain why grazing time of beef cattle does not always decrease with decreasing ambient temperature.

Several factors may account for the apparent difference in winter range use by 7-8 year old and 3 year old cattle. First, 3 year old cattle were not pregnant during Winter 1. Non-pregnant cattle spend less time grazing and select different diets than pregnant cattle (Pfister and Adams, 1993). However, the behavior of the 3 year old cattle over both winters appeared more similar to each other than to the behavior of the 7-8 year old cattle. Second, the turn-in location to the pasture may explain why each group used the pasture as they did. Roath and Krueger (1982) commented that a "characteristic pattern" of movement occurs each year when cattle are turned into a pasture from one gate. Cattle in our study were always turned into the pasture from the same gate. However, cattle used almost all parts of the pasture over both winters. Third, age, irrespective of experience with a resource, may explain our results. The mean daily grazing times of young cattle often differs from that of 7-8 year old cattle (Adams, 1985; Dunn, 1988). Further, young cattle travel more than 7-8 year old cattle (Dunn, 1988). We were unable to control for age versus experience effects.

Finally, experience may explain the general range use patterns that we observed. Our 3 year old cattle may have traveled more to explore the resources in the pasture. Seven-eight year old cattle were already familiar with the type of resources in the pasture and did not need to search as often. Young, inexperienced animals learn a variety of

skills from parents or experienced conspecifics (Edwards, 1976; Thorhallsdottir et al., 1987; Green, 1992; Olson et al., 1992). Social learning enables an animal to use resources more efficiently without having to always explore those resources themselves (Provenza and Balph, 1987). Hunter and Milner (1963) observed that lambs almost always became members of the same home range group as their parents. Early experience with a habitat is important in determining whether mice prefer a specific habitat (Wecker, 1963). Therefore, learning can affect habitat selection.

Conclusion

Experience with winter range apparently influences how animals use forage and thermal resources available to them. This difference in range use could be helpful to managers attempting to match behaviors to a range environment. Cattle herds which are composed of mixed-age groups may use the range more efficiently. Seven-eight year old cattle in our study tended to integrate the forage and thermal resources to find beneficial environments in which to graze or rest. In a free-ranging winter grazing situation with limited supplementation, mixing age groups could shorten the length of time required for 3 year old animals to learn to efficiently use pasture resources (Stuth, 1991). This may improve the production of some livestock, such as replacement females, when moved into a new environment (Zimmerman, 1980).

In addition, allowing animals to take greater advantage of winter range resources can decrease input costs. Based on an economic model, Bates et al. (1990) showed that

winter grazing can yield higher net returns than those obtained by feeding baled hay even during severe winters. In conclusion, site specific forage and thermal resources should be considered when attempting to explain range use and behavior of cattle. Previous experience with winter range may influence cattle use of those resources.

CHAPTER 3

A SIMPLE INDEX OF STANDARD OPERATIVE TEMPERATURE FOR MULE
DEER AND CATTLE IN WINTERIntroduction

Different microclimates across the landscape frequently determine an animal's location (Leckenby and Adams, 1986; Schmidt, 1993; Sargeant et al., 1994). Operative temperature and the related standard operative temperature are often used as biophysical indices of an animal's thermal environment (Bakken, 1980; Parker and Robbins, 1984; Vispo and Bakken, 1993). Operative and standard operative temperature incorporate variables such as ambient temperature, windspeed, and short and long-wave radiation with species-specific variables such as resistance to heat exchange. Thus they more accurately represent the thermal environment that an animal experiences.

Measuring operative temperature or standard operative temperature in the field can be difficult. Measurements usually require expensive equipment which is not easily mobile, or life-like copper mounts of animals (Crawford et al., 1983; Bakken et al., 1985; Bakken, 1992). Because of this, measurements of operative and standard operative temperature are often not recorded at an animal's actual location (Merrill, 1991; Schwab and Pitt, 1991; Demarchi and Bunnell, 1993). Values are extrapolated or modeled from weather stations which rarely share the same thermal characteristics as the animal's location.

Standard operative temperature would be more useful to ecologists and biologists if it could be related to more easily obtained microclimate measurements. Our objective was to determine if appropriate regression equations could incorporate simple micrometeorological data to model standard operative temperature for two large endotherms, mule deer (*Odocoileus hemionus*) and cattle (*Bos taurus*).

Theory of Standard Operative Temperature

Operative temperature (T_e) was first developed by Winslow et al. (1937). It is defined as the "true temperature of an isothermal laboratory enclosure with the same convection properties as the general environment, which would result in the same net sensible heat flow from the animal, assuming the same surface or body core temperature" (Bakken, 1981). Operative temperature is an index of the potential heat flow between the animal and its environment (Bakken, 1980). Operative temperature defined by Campbell (1977) is:

$$T_e = T_a + r_e (R_{abs} - \epsilon_s \delta T_a^4) / \rho c_p \quad (3)$$

where T_a is ambient temperature ($^{\circ}\text{C}$), r_e is a parallel equivalent resistance to convective and radiative heat transfer--essentially the boundary layer resistance, R_{abs} is the net absorbed thermal and solar radiation (W m^{-2}), $\epsilon_s \delta T_a^4$ is the long-wave radiation emitted by the animal, and

ρc_p is the volumetric specific heat of air. Values for these parameters can be obtained from the literature or with inexpensive equipment except for R_{abs} . Net absorbed thermal and solar radiation is defined as:

$$R_{abs} = a_s (A_p / A) S_p + a_s ([\bar{S}_d + S_r] / 2) + a_L (L_s + L_g) / 2 \quad (4)$$

where a_s is the absorptivity to short-wave radiation (W m^{-2}), A_p / A is the ratio of shadow area on a surface perpendicular to the solar beam, S_p is the direct beam radiation on a surface perpendicular to the beam (W m^{-2}), $[\bar{S}_d + S_r] / 2$ is the mean diffuse solar irradiance (scattered and reflected), a_L is the absorptivity to long-wave radiation, and $(L_s + L_g) / 2$ is the mean incoming long-wave irradiance (from sky and ground). Except for L_g , the short and long wave components of the equation can be measured with a solarimeter or pyranometer and a net radiometer. Long wave radiation from the ground can be calculated by measuring the surface temperature of the ground and converting that temperature to long-wave emittance with the Stephan-Boltzmann equation:

$$L_g = \epsilon_g \delta T_g^4 \quad (5)$$

where ϵ_g is the emissivity of the ground, δ is the Stephan-Boltzman constant ($5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$), and T_g is the surface temperature of the ground (K).

Standard operative temperature (T_{es}) is related to T_e but more fully incorporates the effects of windspeed on an animal's resistance to heat loss. Standard operative

temperature defines thermal equivalence between controlled laboratory and natural environments (Bakken, 1981). It is a direct index of sensible heat flux between an animal and its environment (Bakken, 1980). Standard operative temperature is defined as:

$$T_{es} = T_b - [(r_{bs} + r_{es}) / (r_b + r_e)] \cdot (T_b - T_e) \quad (6)$$

where T_b is body temperature ($^{\circ}\text{C}$), r_b is the thermal resistance of skin and insulation (s m^{-1}), r_e is the thermal resistance between outer surface and environment (s m^{-1}), and r_{bs} and r_{es} are the values of r_b and r_e in the standard environment with windspeed $< 1 \text{ m s}^{-1}$ (Bakken, 1981).

Methods

We recorded blackglobe and ambient temperatures, windspeed, net radiation, total radiation, albedo, and ground surface temperature simultaneously in a field in Bozeman, Montana. We periodically recorded weather data from 10 Nov. 1994 to 22 Mar. 1995. These environmental parameters were recorded every ten minutes for intervals of up to one hour. There were thirty-five measurement periods. We recorded different ambient temperatures (-3.5 to 9.75°C), windspeeds (0 to 6.8 m s^{-2}), solar radiation (56 to 406 W m^{-2}), and ground cover (snow or vegetation) to obtain a wide variety of environmental combinations.

Our blackglobe thermometer was a hollow 10.2 cm diameter copper sphere

painted matte black with a mercury thermometer inserted through a rubber stopper into the center of the sphere (Kuehn et al., 1970). Ambient temperature was recorded with a mercury thermometer inserted through a rubber stopper and surrounded by an aluminum shield to keep the thermally sensitive end from being affected by direct solar radiation. Both of these thermometers were attached to a portable tripod with buret clamps 1.3 m above the ground. This distance is approximately shoulder height on a cow (Yousef, 1989). We recorded windspeed (m s^{-1}) at the same height with a hand-held digital anemometer.

We recorded total solar radiation with a solarimeter (Model CM3, Kipp and Zonen) adjacent to the blackglobe and ambient temperature tripod using a 21X Micrologger (Campbell Scientific). Net radiation was also recorded by the micrologger with a net radiometer (Model Q6, Radiation Energy Balance Systems, Inc.). We calculated albedo according to Merrill (1991) by recording total solar radiation, and then inverting the solarimeter to determine the proportion of reflected radiation. We recorded albedo immediately before the other weather measurements. We measured ground surface temperature directly beneath the blackglobe and ambient thermometers with a hand-held infrared thermometer (Model 08407-20, Cole Parmer).

To develop a simple index of T_{es} , we first calculated T_{es} for mule deer and cattle in winter using species-specific resistance values estimated by Parker and Gillingham (1990) and Webster (1970) respectively (Appendix). Second, we regressed T_{es} for each species with windspeed, blackglobe and ambient temperature, and the quadratic, cubic and logarithmic terms of these variables (SAS, 1988). Third, we compared the calculated

value of T_{es} (eq. 6) with the predicted regression value using Pearson's correlation coefficient.

Finally, we compared our mule deer model with data derived from Parker and Gillingham (1990) which estimates T_{es} for mule deer in winter. They modeled T_{es} at a variety of ambient temperatures (-25 to 5°C), short-wave radiation levels (0 to 400 W m⁻²), and windspeeds (0 to 11.6 m s⁻¹). Since their model encompassed a wider range of temperature, radiation, and windspeeds than our observations, we selected combinations of environmental parameters from their data which were similar to our own ($n=36$) and compared our model with this partial data set. We then applied our model to their expanded data set, except when short-wave radiation was zero, to see how our model predicted T_{es} under more extreme conditions ($n=112$).

Parker and Gillingham (1990) modeled T_{es} in snow-free and snow-covered environments. Therefore, we compared T_{es} from our regression model to Parker and Gillingham's estimates of T_{es} in snow-free and snow-covered environments with the Pearson's correlation coefficient, and Cochran's t-test.

Results

We found that similar multiple regression models estimated T_{es} for mule deer and cattle. Standard operative temperatures for mule deer in winter (T_{esd}) were estimated with the model:

$$T_{esd} = 1.545(T_a) + 0.714(T_g) - 3.215(\mu) + 2.438 \quad (7)$$

where T_a is ambient temperature ($^{\circ}\text{C}$), T_g is blackglobe temperature ($^{\circ}\text{C}$), and μ is windspeed (m s^{-1}). The adjusted R^2 was 0.96. The predicted and calculated (eq. 6) values of T_{es} for mule deer were highly correlated ($P=0.0001$; Fig. 4).

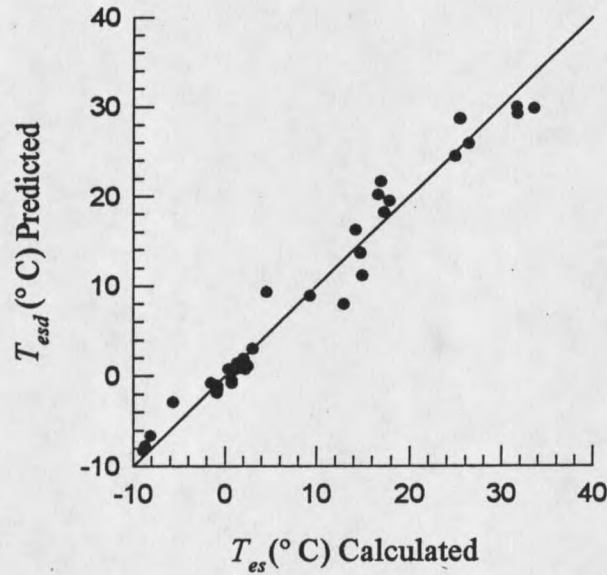


Figure 4. Relationship between calculated standard operative temperature for mule deer and predicted standard operative temperature from the mule deer regression model. The solid line represents a slope of 1. Pearson's correlation coefficient is shown.

Standard operative temperatures for cattle in winter (T_{esc}) were estimated with the model:

$$T_{esc} = 1.197(T_a) + 1.042(T_g) - 3.715(\mu) + 4.739 \quad (8)$$

where the units for ambient and blackglobe temperature, and windspeed are the same as in equation 7. The adjusted R^2 of the cow model was 0.94. The predicted and calculated values of T_{es} for cattle were highly correlated ($P=0.0001$; Fig. 5).

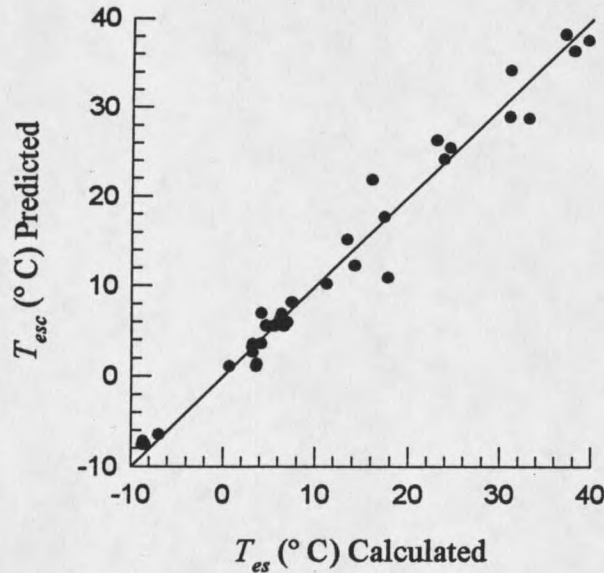


Figure 5. Relationship between calculated standard operative temperature for cattle and predicted standard operative temperature from the cattle regression model. The solid line represents a slope of 1. Pearson's correlation coefficient is shown.

Standard operative temperatures predicted from our regression model with the partial data set were highly correlated with T_{es} of Parker and Gillingham ($P=0.0001$) in snow-free and snow-covered environments. The mean T_{esd} from our regression model in snow-free and snow-covered environments were similar to the mean T_{es} of Parker and Gillingham's models ($P=0.70$, $P=0.37$, respectively). The mean difference between T_{esd} from our regression model and Parker and Gillingham's estimate of T_{es} in snow-free environments was $-1.22 \pm 0.46^{\circ}\text{C}$ (SE). The mean difference between T_{esd} from our regression model and Parker and Gillingham's estimate of T_{es} in snow-covered

environments was $-2.99 \pm 0.70^{\circ}\text{C}$ (SE).

Standard operative temperatures predicted from our regression model with the expanded data set were also highly correlated with T_{es} of Parker and Gillingham ($P=0.0001$) in snow-free and snow-covered environments. The mean T_{esd} from our regression model in the snow-free environment was similar to the mean T_{es} of Parker and Gillingham's model ($P=0.52$). The mean T_{esd} from our regression model in the snow-covered environment differed from the mean T_{es} of Parker and Gillingham's model when windspeeds of zero were included ($P=0.05$). In contrast, the mean T_{esd} from our regression model in the snow-covered environment was similar to the mean T_{es} of Parker and Gillingham's model when windspeeds of zero were excluded ($P=0.26$).

With the expanded data set, the mean difference between T_{esd} from our regression model and Parker and Gillingham's estimate of T_{es} in snow-free environments was $-1.86 \pm 0.47^{\circ}\text{C}$ (SE). The mean difference between T_{esd} from our regression model and Parker and Gillingham's estimate of T_{es} in snow-covered environments was $-5.76 \pm 0.58^{\circ}\text{C}$ (SE).

Discussion

Similar to other studies, our mule deer and cow regression models predicted T_{es} well with adjusted $R^2 > 0.95$. Standard operative temperatures calculated from microclimate data and T_{es} measured with a red-winged blackbird copper mount are highly correlated ($R=0.94$; Bakken et al., 1985). Operative temperatures from a multiple

regression model similar to our model accurately predicted T_e of a copper mount of the aquatic turtle *Pseudemys scripta* ($R^2=0.90$; Crawford et al., 1983).

The similarity between our mule deer model of T_{esd} and Parker and Gillingham's (1990) data indicates that our model accurately predicts T_{es} under a wide variety of winter conditions. In general our model slightly underestimated T_{es} compared with Parker and Gillingham's estimates ($\approx 0 - 5^\circ\text{C}$) in snow-free and snow-covered environments. This difference was especially noticeable when ambient temperatures were below -5°C , the ground was snow-covered, and windspeeds were zero. Under these conditions, the difference between our mule deer model and Parker and Gillingham's predictions of T_{es} was as great as 18°C . This may reflect that our model used actual ground temperature to calculate long-wave radiation emitted from the ground (eq. 5) whereas Parker and Gillingham used air temperature. In our study, the mean ground temperature was $-3.54 \pm 0.97^\circ\text{C}$ (SE) whereas the mean air temperature was $2.96 \pm 0.83^\circ\text{C}$ (SE). If we had used air temperature to solve for long-wave radiation from the ground, the mean T_{es} of mule deer would have been $11.17 \pm 2.29^\circ\text{C}$ (SE). Because we used ground temperature to solve for long-wave radiation from the ground, the mean T_{es} of mule deer was $8.48 \pm 2.05^\circ\text{C}$ (SE).

The difference in T_{es} calculated with ground temperature and air temperature is probably the reason that T_{esd} calculated with the expanded data in snow-covered environments was different from that predicted by Parker and Gillingham. However, when windspeeds were greater than zero there was no difference. Standard operative temperature is highly sensitive to windspeed (Parker and Gillingham, 1990). As

windspeed increases T_{es} decreases when ambient temperature, and solar and thermal radiation are constant. Apparently windspeed negated the difference due to colder ground temperatures.

We did not have an independent data set to validate our estimates of cattle T_{es} . However, our cattle regression model is similar to the mule deer model with respect to independent variables and R^2 values. Therefore we believe that the cattle model would accurately predict T_{es} in conditions similar to those in which it was derived, and similar to those described by Parker and Gillingham (1990).

The range of T_{es} predicted by our models was greater for cattle than it was for mule deer. Standard operative temperatures of cattle may have been warmer than those of mule deer because cattle absorb more short-wave radiation than mule deer (Campbell, 1977; Parker and Gillingham, 1990; Appendix). Standard operative temperatures of cattle were similar to those of mule deer under windy conditions. This indicates that although cattle have higher whole body thermal resistance and relatively less surface area exposed to convective heat loss than mule deer, the insulation of their coat is disrupted by wind more than the insulation of a mule deer's coat. White-tail deer have approximately 900 guard hairs cm^{-2} in winter, and individual hairs are approximately 0.25 mm (Moen and Severinghaus, 1984). Hereford cattle have approximately 210 guard hairs cm^{-2} in winter, and individual hairs are approximately 45.3 μm (Peters and Slen, 1964).

Regression models can be appropriate for predicting T_{es} of animals in various environments (Bakken, 1992). However, they have limitations. Regression models provide different estimates of T_{es} than appropriate taxidermic mounts. This may be

particularly relevant when microclimate data are used as the standard (Bakken et al., 1985). Further, regression models are species-specific and limited to the type of conditions from which they were developed.

However, measuring T_{es} at or near the location of free-ranging mule deer or cattle in winter would be difficult with micrometeorological equipment or taxidermic metal mounts. As a result, scientists often use air temperature to express an animal's thermal environment (Hidiroglou and Lessard, 1971; Dunn et al., 1989; Prescott et al., 1994). Integrating air temperature, windspeed, and solar and thermal radiation with an animal's thermal resistance is a more accurate indicator of an animal's environment (Spotila and O'Connor, 1992).

Integrating appropriate environmental parameters has practical advantages which may help explain animal behavior relative to weather. For example, the mean daily grazing time of cattle has been shown to be sensitive and insensitive to decreasing ambient temperatures in different studies (Adams, 1985; Dunn et al., 1989). Ambient temperature is not an accurate index of the thermal environment experienced by an animal (Senft and Rittenhouse, 1985). In our study, the mean differences between T_{es} and ambient temperature for cattle and mule deer were $7.37 \pm 0.93^{\circ}\text{C}$ (SE) and $5.52 \pm 1.55^{\circ}\text{C}$ (SE), respectively. However, there were twelve instances with cattle, and twelve instances with mule deer when the difference between T_{es} and ambient temperature was greater than 10°C . On nine occasions with cattle, and three occasions with mule deer, the difference between T_{es} and ambient temperature was greater than 20°C . Using T_{es} rather than ambient temperature, relative humidity, or windspeed alone may help explain some

of the discrepancies in animal behavior relative to their thermal environment.

Conclusion

We realize that our models of T_{es} for mule deer and cattle are probably not applicable to other seasons, or to all possible winter conditions. However, under the conditions for which they apply they may more accurately represent an animal's thermal environment than many commonly used weather measurements. The required environmental sensors are robust, portable, and relatively inexpensive. Thus, our models make T_{es} more accessible to scientists interested in mule deer or cattle behavior in winter environments.

CHAPTER 4

DIET SELECTION BY CATTLE ON NATIVE WINTER RANGE IN MONTANA

Introduction

Grazing cattle on winter range with minimum inputs can reduce production costs without reducing performance (Bates et al., 1990). However, forage quality is unevenly distributed within a pasture and within a plant. In summer cattle are able to select diets of better quality than the average quality on rangelands (Hardison et al., 1954). In winter diet selection is inhibited by overall poor forage quality (Stuth, 1991). Managers may be able to improve the quality of winter forage by grazing, burning or fertilizing during the growing season (Anderson et al., 1990; Jourdonnais and Bedunah, 1990; Willms, 1991). This may allow livestock an opportunity to select higher quality diets on winter range than are usually present. Cattle have higher weight gains and production efficiency with higher quality forages in summer and winter (Cook and Harris, 1977; Beaty and Engel, 1980).

The amount of green material in a forage sample should be an index of its nutritional quality (Launchbaugh, et al., 1990). Green herbage of Idaho fescue (*Festuca idahoensis*) and bluebunch wheatgrass (*Agropyron spicatum*) has a higher nutritive content at all times of the year compared with dead forage (Houseal and Olson, personal comm.).

Our objective was to determine if cattle select diets of higher quality than are present in two native bunch grasses, Idaho fescue (*Festuca idahoensis*) and bluebunch wheatgrass (*Agropyron spicatum*), on native winter range by comparing the amount of green material in rumen samples with the amount of green material in randomly selected grasses of each species.

Methods

The study site is a 324 ha pasture on the Montana Agricultural Experiment Station Red Bluff Research Ranch (latitude 45° 35'N, longitude 111° 39'W) near Norris, Montana. The pasture is dominated by a *Festuca idahoensis*/*Agropyron spicatum* habitat type (Mueggler and Stewart, 1980), and is typified by shallow range sites and rocky outcrops. Elevation ranges from 1400 to 1900 m. We established twelve 30 m transects within the pasture stratified by slope position. Four transects were on upper slopes, four transects were on mid-slopes, and four transects were on lower slopes. We sampled forages on 11 Dec. 1994, 14 Jan. 1994, 4 Mar. 1994 (Winter 1), and 12 Jan. 1995 (Winter 2). We sampled once in Winter 2 because the seasonal variation in the percent green material in Winter 1 was low. In addition, the amount of green material in Winter 2 was low, as it was in Winter 1. At each transect we randomly located and then clipped three plants of Idaho fescue, and three plants of bluebunch wheatgrass to ground level. We dried these samples in a forced air oven at 37°C for 5 to 7 days. We then composited samples of each species by transect and date.

Within a week of clipping forage samples, we evacuated the rumens of six pregnant Angus x Hereford cattle in Winter 1, and seven in Winter 2. We allowed cattle to graze for 45 min to 1 h, and removed the forage they had consumed. We then returned their rumen contents. We air-dried rumen samples for 7 - 10 days. Rumen samples, and the Idaho fescue and bluebunch wheatgrass samples were ground through a 5 mm screen on a Wiley Mill.

We then evenly spread a 0.25 g sample of rumen contents, or Idaho fescue, or bluebunch wheatgrass on a gridded petri dish. There were forty-four intersection points on the grid. At each intersection point, we recorded hits of green material to determine the percentage of green herbage in each sample.

We determined the accuracy of this method by establishing a relationship between a known amount of green material, and the number of counts of green material of the same sample on the gridded petri dish with each species. We created samples from 0% green material to 100% green material in 10% increments. All samples weighed 0.25 g. We regressed the known weight of green material in each sample with the number of counts of green material on the grid for Idaho fescue and bluebunch wheatgrass ($R=.98$, $R=.96$, respectively). We used planned linear contrasts to determine if the percentage of green material was different between rumen samples and Idaho fescue, and between rumen samples and bluebunch wheatgrass within sampling periods (SAS, 1988).

Results

The percentage of green material in Idaho fescue was greater than that in the rumen contents during all sampling periods both winters ($P < .05$). Bluebunch wheatgrass had similar amounts of green material compared with rumen contents during all sampling periods of both winters ($P > .05$) except in January of Winter 1. During this period the percentage of green material in bluebunch wheatgrass was less than that in the rumen ($P = .05$; Fig. 6).

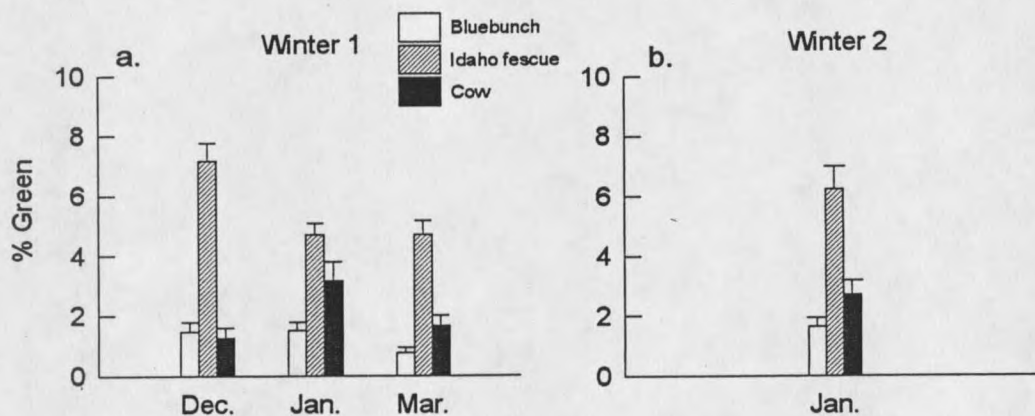


Figure 6. The percentage of green material in bluebunch wheatgrass (bluebunch), Idaho fescue (Idaho), and cattle rumen contents (Cow) during Winter 1, and Winter 2.

Discussion

During the growing season cattle are often able to select higher quality diets than

that available (Hardison et al., 1954). Our data indicates that during winters when little green material is present cattle do not select higher quality diets than that present in Idaho fescue and bluebunch wheatgrass. This is similar to other findings regarding diet selection by cattle on winter ranges (Van Dyne et al., 1964; Wallace et al., 1970). During January of Winter 1, cattle had more green material in their rumens than was present in bluebunch wheatgrass, possibly because they grazed other species, such as Idaho fescue, more frequently and thus ingested a greater proportion of green material.

The inability of cattle to select higher quality diets than that generally present in Idaho fescue and bluebunch wheatgrass in winter may be due to several features of senescent forage, and the structure of a cow's mouth. Idaho fescue and bluebunch wheatgrass in particular are stemmy in winter. Flores et al. (1993) found that a high number of stems, a high density of stems, or both in a sward reduces the ability of cattle to select high quality diets. Further, Idaho fescue and bluebunch wheatgrass plants that are not grazed during the growing season or only partially grazed, have green leaves interspersed with more numerous dead leaves. Thus, green leaves are protected from grazing by residual stems and leaves.

The structure of a cow's mouth restricts the animal's ability to finely manipulate forages. Cattle have relatively wide muzzles and upright incisors which limit their ability to graze a grass tuft selectively (O'Reagain and Mentis, 1989). In addition, cattle sweep forage into their mouth with their tongue which further restricts their ability to select certain plant parts over others (Illius and Gordon, 1987).

The percent of green material in Idaho fescue and bluebunch wheatgrass during

our study was low. However, during September of 1993 and 1994 precipitation was 62% and 18% of normal respectively. Normal precipitation levels and moderate temperatures will stimulate more fall growth which cattle may be able to select. Some livestock producers are interested in increasing the utilization of standing forages in winter (Peck, 1991). Managers could increase the overall diet quality of the pasture through grazing, burning, or some other method during the growing season.

CHAPTER 5

SUMMARY

Seven-eight year old, experienced cattle preferred to use protected or moderately protected areas in the pasture and avoided unprotected areas. Because of this, 7-8 year old cattle were often in areas warmer than the coldest measured points in the pasture and avoided areas that had conditions below their lower critical temperature. Three year old cattle were often in the coldest parts of the pasture and consequently did not always avoid areas which were below their lower critical temperature. Seven-eight year old cattle matched their behavior to the available forage resources more efficiently than the 3 year old, inexperienced cattle. During Winter 2, 7-8 year old cattle may have overmatched their grazing behavior to the forage resources in protected areas to avoid high winds. Seven-eight year old, experienced cattle may have lost less weight and condition during Winter 2 than 3 year old, inexperienced cattle because they matched their behavior to the available resources in the pasture more closely. Efficient use of a habitat is possibly learned.

Standard operative temperature can be accurately estimated for mule deer and cattle in winter with simple micrometeorological equipment. Scientists can use standard operative temperature as a more accurate index of a mule deer or cow's thermal environment in winter than ambient temperature, windspeed, or relative humidity alone. This may help explain mule deer or cattle behavior in winter relative to weather.

During some fall seasons native bunchgrasses produce low amounts of green herbage. In addition, the structure of senescent forage and of a cow's mouth limit the animal's ability to select higher quality diets than that generally present in Idaho fescue and bluebunch wheatgrass in winter. Managers may be able to improve the overall nutritional quality of winter pastures by grazing, burning or some other method during the growing season.

Winter range in Montana challenges an animal's ability to avoid cold stress, and to graze enough high quality forage. Apparently 7-8 year old, experienced cattle are more adept at winter range use than are 3 year old, inexperienced cattle. However, because of plant structure and cattle mouth structure, neither age group may be able to obtain higher quality diets than that generally available on winter range.

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APPENDIX

Calculation of standard operative temperature for mule deer and cattle in winter.

$$T_{es} = T_b - [(r_{bs} + r_{es}) / (r_b + r_e)] \cdot (T_b - T_e) \quad (\text{Bakken, 1981})$$

where:

T_b = body temperature of mule deer (38.0 °C; Parker and Robbins, 1984)
or body temperature of cattle (38.6 °C; Christopherson et al., 1979)

r_b = thermal resistance of skin and insulation (s m^{-1})

r_e = thermal resistance between outer surface and environment (s m^{-1})

r_{bs} = value of r_b in the standard environment (s m^{-1}), windspeed < 1 m s^{-1}

r_{es} = value of r_e in the standard environment (s m^{-1}), windspeed < 1 m s^{-1}

and;

$$T_e = T_a + r_e (R_{abs} - \epsilon_s \delta T_a) / \rho c_p \quad (\text{Campbell, 1977})$$

with:

T_a = air temperature (°C)

R_{abs} = total absorbed short and long-wave radiation (W m^{-2})

$\epsilon_s \delta T_a^4$ = long-wave radiation emitted by animal (W m^{-2})

ϵ_s = emissivity of surface (1.0 for mule deer; Parker and Gillingham, 1990)
or (1.00 for cattle; assumed to be similar to mule deer)

δ = Stephan-Boltzman constant ($5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$)

T_a^4 = ambient temperature (K)

ρc_p = volumetric specific heat of air ($1200 \text{ J m}^{-3} \text{ K}^{-1}$)

Absorbed Short and Long-Wave Radiation (R_{abs}):

$$R_{abs} = \alpha_s (A_p / A) S_p + \alpha_s (S_d + S_r) / 2 + \alpha_L (L_s + L_g) / 2 \quad (\text{Campbell, 1977})$$

where:

α_s = absorptivity to shortwave radiation (W m^{-2}); .80 for mule deer in winter
(Parker and Gillingham, 1990), .89 for angus cattle (Campbell, 1977)

(A_p/A) = ratio of the shadow area on a surface perpendicular to the solar beam
(.30; Campbell, 1977)

S_p = direct beam radiation on a surface perpendicular to the beam (W m^{-2})

S_d = diffuse short-wave radiation (W m^{-2})

S_r = reflected short-wave radiation from ground (W m^{-2}), the product of albedo and total shortwave radiation

a_L = absorptivity to long-wave radiation; equal to ϵ_s for both species

L_s = long-wave radiation from the sky (W m^{-2})

L_g = long-wave radiation from the ground (W m^{-2})

Long-wave radiation from sky and ground ($L_s + L_g$):

S_t = total incident short-wave solar radiation (W m^{-2})

L_g = $\epsilon_g \delta T_g^4$; where ϵ_g is the emissivity of the ground, (.91 for snow and .97 for bare ground), and T_g is the temperature of the ground surface in K

L_s = $(S_t + L_s - S_r + L_s) + S_r + L_g - S_t$; where $(S_t + L_s - S_r + L_s)$ is measured with a net radiometer, and S_t is measured with a solarimeter or pyranometer

Diffuse and direct short-wave radiation (S_d, S_p) using Erbs et al., equation (1982):

S_o = solar constant (1360 W m^{-2})

S_x = S_t/S_o

S_{dif} = the fraction of diffuse radiation to total short-wave solar radiation

if $S_x \leq .22$ then $S_{dif} = 1 - .09(S_x)$

if $S_x \leq .80$ then $S_{dif} = .9511 - .1604(S_x) + 4.388(S_x^2) - 16.638(S_x^3) + 12.336(S_x^4)$

if $S_x > .80$ then $S_{dif} = .165$

S_d = $S_{dif} \cdot S_t$

S_p = $S_t - S_d$

Thermal resistance between outer surface and environment (r_e):

r_e = $r_{Ha} \cdot r_f / r_{Ha} + r_r$

r_r = $\rho c p / 4 \epsilon_s \delta T_a^3$

r_{Ha} = $307 \sqrt{d/\mu} \cdot .7$

$$r_{Hasun} = 840[d/(T_{s(sun)} - T_a)]^{.25}$$

$$r_{Hashade} = 840[d/(T_{s(shade)} - T_a)]^{.25}$$

where:

r_r = resistance to radiative heat transfer (T_a in K)

r_{Ha} = resistance to forced convective heat transfer

r_{Hasun} = resistance to free convection in sun (T_a in °C)

$r_{Hashade}$ = resistance to free convection in shade (T_a in °C)

μ = wind speed in $m\ s^{-1}$

d = characteristic dimension of animal; .61 for 65 kg mule deer (Parker, 1987), 1.1 for mature cow (calculated from Guilbert and Gregory, 1952)

T_s = mean skin temperature in sun or shade in winter; for mule deer 36 and 32 °C respectively (Parker and Robbins, 1984), for cattle 32 and 27 °C respectively (Beaver and Olson, unpubl.)

Whole body thermal resistance for mule deer in winter (r_{bs}):

$$r_{bs} = 857.9 - 29.9(T_e) - 0.19(T_e^2) + 0.006(T_e^3); \text{ (Parker and Gillingham, 1990)}$$

$$r_t = 63.95 - 5.58(T_e)$$

$$r_{cs} = r_{Hbs} - r_{Ht}$$

where:

r_t = thermal resistance of the tissue

r_{cs} = thermal resistance of the coat under low convective conditions ($\mu < 1\ m\ s^{-1}$)

Whole body thermal resistance to outdoor wind speeds for mule deer in winter (r_b):

$$r_c = r_{cs}/(1.0 + 0.08\mu)$$

$$r_b = r_t + r_c$$

where:

r_c = thermal resistance of the coat under ambient wind speeds

Whole body thermal resistance for cattle in winter (r_{bs}) from Webster (1970):

$$I_{es} = 11.78 + .24D - 2.5$$

$$I_t = 5.5 + 0.018(w) + 0.099(T_a)$$

$$r_{bs} = I_{es} + I_t$$

where:

$$D = \text{coat depth in mm; assumed 23 mm (Blaxter and Wainman, 1970)}$$

$$w = \text{weight of animal in kg (assumed 550 kg)}$$

$$T_a = \text{ambient temperature (}^\circ\text{C)}$$

Whole body thermal resistance to outdoor wind speeds for cattle in winter (r_b):

$$I_e = 11.78 + .24D - .49u^5$$

$$I_t = 5.5 + 0.018(w) + 0.099(T_a)$$

$$r_b = I_{es} + I_t$$

where:

$$u = \text{wind speed in m min}^{-1}$$

note: I_{es} and I_e include r_{es} and r_e respectively (Webster, 1971). Therefore, for cattle:

$$T_{es} = T_b - (r_{bs}/r_b) \cdot (T_b - T_e)$$