NUTRITONAL CONDITION OF ADULT FEMALE SHIRAS MOOSE IN NORTHWEST WYOMING

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ABSTRACT: The "animal indicator concept" assumes that because an animal is a product of its environment, it likely reflects the quality of its environment. Although this concept has been applied to assess population condition and habitat quality for Alaskan moose (*Alces alces gigas*), to our knowledge this is the first time it has been used to assess the nutritional status of a Shiras moose (*A.a. shirasi*) population. We investigated the physical condition and nutritional status of adult (≥ 2 years) female Shiras moose captured in northwest Wyoming during the winters of 2005-2007. Rump fat depth was measured via ultrasonography and biological samples were collected and analyzed for hematology, serum chemistry, micro- and macronutrients, endo- and ectoparasites, and bacterial and viral serology. Five blood parameters believed to be important predictors of moose condition (packed cell volume, total serum protein, hemoglobin [Hb], calcium [Ca], and phosphorous [P]) were compared to data from Alaskan moose considered to be in average-above average condition. Micro- and macronutrient values were evaluated based on published deficiency levels for domestic herbivores. We conducted a correlation analysis to determine if a significant relationship existed between hematological and serum chemical parameters and rump fat depth. Mean rump fat depth did not differ among years and was greater than reported values for Alaskan moose. However, a high proportion of sampled moose had Hb, Ca, and P values lower than Alaskan moose that were considered to be in average condition. Hair and serum micro- and macronutrient analyses indicated a high proportion of moose were potentially deficient in copper, zinc, manganese, and P. We observed a marginally significant relationship between depth of rump fat and two serum chemical parameters (aspartate amimotransferase and lactate dehydrogenase). The results are suggestive of a Shiras moose population in marginal physical condition that is probably related to less than optimal habitat quality. These findings should assist managers in evaluating the health of Shiras moose populations throughout their range.

ALCES VOL. 46: 151-166 (2010)

Key words: *Alces alces shirasi*, condition, disease, hair, hematology, moose, nutrients, nutrition, parasites, rump fat, serum chemistry, ultrasound, Wyoming.

The "animal indicator concept" is used to provide managers with a relative index of population health with respect to habitat carrying capacity (Franzmann 1985). This approach assumes that an animal is a product of its environment and therefore will reflect the quality of its environment. Early work focused on hematological and serum chemical parameters to assess differences in habitat quality among populations of pronghorn antelope (*Antilocapra americana*; Seal and Hoskinson 1978), white-tailed deer (*Odocoileus virginianus*; Seal et al. 1978), and elk (*Cervus elaphus*; Weber et al. 1984). Franzmann and LeResche (1978) expanded this concept by evaluating blood parameters in relation to in-

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dices of physical condition for Alaskan moose (*Alces alces gigas*). This provided managers with baseline data that could be used to assess population condition, potential reproductive performance, and ultimately, habitat quality (Franzmann and Schwartz 1985, Stephenson 2003). Packed cell volume (PCV) was the single best predictor of body condition in moose, followed by hemoglobin (Hb), total serum protein (TSP), calcium (Ca), and phosphorous (P; Franzmann and LeResche 1978). Although the value of using TSP, Ca, and P has been questioned (Keech et al. 1998), these 5 blood parameters were effective in identifying populations at the extremes (i.e., very good or very poor condition), but were less effective when used to compare populations in moderate condition (Franzmann et al. 1987). More recently, ultrasonic measurements of rump fat depth have been used to successfully quantify moose condition and reproductive success (Stephenson et al. 1998, Testa and Adams 1998, Keech et al. 2000).

Even if an animal appears to be in relatively good physical condition, nutritional deficiencies can create physiological imbalances that may affect population performance (Combs 1987, Gogan et al. 1989). Due to high variability in forage mineral concentrations among sites and seasons, free-ranging herbivores rarely acquire sufficient quantities of particular nutrients (McDowell 2003). The nutritional quality of moose browse is most limited during winter (Kubota et al. 1970, Oldemeyer et al. 1977, Ohlson and Staaland 2001) and mineral concentrations in moose hair show similar temporal trends (Franzmann et al. 1974, Flynn et al. 1977, Stewart and Flynn 1978, Flynn and Franzmann 1987). Mineral deficiencies can lead to reduced survival, especially among calves and yearlings, and reduced reproductive output in domestic herbivores (WallisDeVries 1998). Although clinical deficiencies are difficult to diagnose in wild ungulate populations, deficiencies of trace elements, specifically Cu, have been suggested as a contributing factor to moose population declines in Alaska (Flynn et al. 1977, O'Hara et al. 2001), Minnesota (Custer et al. 2004), and Sweden (Frank et al. 1994).

Indices of calf recruitment and population density suggest a downward trend in Shiras moose (*A.a. shirasi*) numbers in northwest Wyoming (Brimeyer and Thomas 2004, Becker 2008). Several factors have been hypothesized as contributing to this decline (Brimeyer and Thomas 2004), but no systematic approach has been implemented to evaluate these factors. To address the issues of habitat quality, disease, and parasites, we used the animal indicator concept to describe the physical condition and nutritional status of adult ($\geq$ 2 years) female Shiras moose via a suite of physiological parameters. Although Houston (1969) and Kreeger et al. (2005) previously reported blood parameter values for Shiras moose in Wyoming, to our knowledge, this study is the first to use the animal indicator concept to assess the condition of a Shiras moose population. Therefore, this work provides data that will aid managers in future evaluation of Shiras moose populations throughout their range. Our research objectives were to: 1) compare hematological and serum chemical parameters to baseline data from Alaskan moose, 2) evaluate the relative condition of the moose herd from ultrasonic rump fat measurements, 3) test for a relationship between rump fat depth and hematological and serum chemical parameters, 4) examine micro- and macronutrient content of moose serum and hair and compare to reported deficiency values for domestic ruminants, 5) evaluate the presence of infectious diseases, and 6) assess endo- and ectoparasite loads.

STUDY AREA

The study area was centered in the Buffalo Valley (43° 42' N, 110° 22' W) approximately 50 km north of the town of Jackson, Wyoming, USA. It encompassed nearly 6,400 km^2 of predominately public land in northwest Wyo-

ming and included portions of Grand Teton National Park, Yellowstone National Park, and the Bridger-Teton National Forest where elevations ranged from 1,866-4,197 m. The climate was characterized by short, cool summers and cold winters (Houston 1968). In general, sagebrush (*Artemisia* spp.) dominated the valley floors while coniferous forests and open forest parks were the most abundant vegetation types at moderate elevations (Knight 1994); alpine tundra occurred at the highest elevations. Riparian areas were characterized by willow (*Salix* spp.) interspersed with narrowleaf cottonwood (*Populus angustifolia*) at lower elevations and on more mesic sites at higher elevations. Moose in the study population wintered in low-elevation, riparian-dominated habitats along the Snake River and its primary tributaries (Becker 2008). During summer, migratory moose traveled to more dispersed, mid-elevation ranges (Becker 2008), whereas non-migratory individuals remained on low elevation ranges (Houston 1968).

METHODS

Adult female moose were captured on winter range in January-March, 2005-2007. They were darted from the ground or helicopter and immobilized with 10-mg thiafentanil (A-3080, Wildlife Pharmaceuticals Inc., Fort Collins, Colorado, USA; McJames et al. 1994, Arnemo et al. 2003, Kreeger et al. 2005) in 2005 and 2006, and 10-mg carfentanil (Wildnil, Wildlife Pharmaceuticals Inc., Fort Collins, Colorado, USA; Kreeger 2000) in 2007. Samples were collected and moose were fitted with global positioning system (model TGW-3700, Telonics, Mesa, Arizona, USA) or very high frequency radio transmitters (model M2710, Advanced Telemetry Systems, Isanti, Minnesota, USA). Once handling was completed, thiafentanil and carfentanil were antagonized with an intramuscular injection of 300-mg naltrexone (Trexonil, Wildlife Pharmaceuticals, Fort Collins, Colorado, USA; Kreeger et al. 2005). Captures were performed in accordance with approved University of Wyoming Animal Care and Use Committee protocols (approved 2005, 2006, 2007).

We collected approximately 50-ml of blood from each moose via jugular venipuncture for hematological analyses, serum chemical analyses, serum trace element screen, and bacterial and viral serology. Hematological analyses included whole blood concentrations of PCV, Hb, mean corpuscular hemoglobin content (MCHC), red blood cells (RBCs), total white blood cells (WBCs), composition of white blood cells, and platelets. Serum chemical analyses included concentrations of albumin (ALB), alkaline phosphate (ALP), aspartate aminotransferase (AST), blood urea nitrogen (BUN), creatine kinase (CK), gamma-glutanyl transferase (GGT), globulins (Glob), glucose (Gluc), lactate dehydrogenase (LDH), TSP, and the macronutrients Ca, magnesium (Mg), and P.

Levels of 5 micronutrients were analyzed with serum trace element screens and included Cu, iron (Fe), manganese (Mn), molybdenum (Mb), and zinc (Zn). Blood was analyzed for the presence of antigens against *Leptospira*, infectious bovine rhinotracheitis virus, bovine viral diarrhea virus, parainfluenza-3 virus, and bovine respiratory syncytial virus in 2005; analysis was conducted for *Brucella abortus* in 2005, 2006, and 2007. Hair samples were collected from the dorsal midline between the shoulders and analyzed for concentrations of arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), cobalt (Co), Cu, Fe, lead (Pb), Mn, mercury (Hg), Mb, nickel (Ni), selenium (Se), thallium (Tl), vanadium (V), tin (Sn), and Zn.

Fecal samples and ear swabs were collected to evaluate endo- and ectoparasite loads. Although encapsulation would have resulted in few, if any, fluke eggs transported through the feces, fecal examinations were used to assess their presence, particularly the giant liver fluke (*Fascioloides magna*) which is undocumented in Wyoming and the com-

mon liver fluke (*Fasciola hepatica*) which is considered rare. A 30-second tick count was performed along the dorsal midline posterior to the neck of each moose to estimate the severity of winter tick (*Dermacantor albipictus*) infestations. All diagnostic analyses were performed at the Wyoming State Veterinary Laboratory (Laramie, Wyoming, USA).

Body condition was subjectively evaluated and a score from 0-10 was assigned to each moose (Franzmann 1977). Depth of rump fat was measured with electronic calipers to the nearest 0.1 cm using an Omega I portable ultrasound unit (E.I. Medical, Loveland, Colorado, USA) in 2005 and a Bantam XLS portable ultrasound unit (E.I. Medical, Loveland, Colorado, USA) in 2006 and 2007. We measured to the midpoint between the coxal tuber (hip bone) and the ischial tuber (pin bone), then located maximum rump fat depth from that point. Maximum rump fat depth was closer to the ischial tuber than the coxal tuber in all cases; however, since our starting point differed slightly from that described by Stephenson et al. (1993, 1998), the measurement was further away from the spine and it was unknown how this might affect subsequent comparisons with other data.

Blood parameter (hematological and serum chemical) values and mineral concentrations (serum and hair micro- and macronutrients) for all moose were pooled within years. Annual means for PCV, Hb, TSP, Ca, and P were compared to baseline data for Alaskan moose that were considered to be in average-above average condition (Franzmann and LeResche 1978); we report the proportion of the sampled population below these baseline values. Micro- and macronutrient requirements for moose have not been established, so the proportion of the sampled population that was deficient was estimated based on published deficiency thresholds for domestic ruminants (Puls 1994, McDowell 2003). The published reference values for Ca (8.0 mg/dl) and Mg (1.8 mg/dl) are not true deficiency thresholds and only represent the lower normal limit for domestic ruminants (Puls 1994, McDowell 2003).

We chose moose-year as our sample unit because we expected among-year variation in female reproductive status (i.e., cost of lactation) and environmental conditions (i.e., winter severity, summer productivity) to have a dominant influence on individual condition. Since rump fat measurements are representative of the variation that can be expected in adult female moose condition among years (Testa and Adams 1998, Keech et al. 2000, Boertje et al. 2007), we plotted rump fat depth for moose sampled in 2 ($n = 5$) or 3 ($n = 2$) years against moose sampled in only one year. This allowed us to evaluate if repeated measures from the same moose over multiple years tended to cluster (suggesting a lack of independence) or were variable among years (Schwartz et al. 2010). Visual inspection of plots showed that rump fat of moose sampled in multiple years was as variable as moose sampled only once, suggesting that moose-year was an appropriate sampling unit. We used a one-way analysis of variance and a Tukey's Honestly Significant Difference (HSD) test to examine among year differences ($\alpha = 0.05$) in rump fat depth, body condition scores (BCS), all blood parameters, and micro- and macronutrients that were above the minimum detection limit (MDL) in order to quantify between-year variations. We conducted a Spearman rank correlation analysis ($\alpha = 0.05$) with Bonferroni corrections to determine if a significant relationship existed between hematological ($\alpha = 0.001$) and serum chemical parameters ($\alpha = 0.004$) and depth of rump fat. All statistical analyses were performed with Statistix 8.0 software (Analytical Software, Tallahassee, Florida, USA).

RESULTS

Moose Capture, Rump Fat, Disease, and Parasites

Forty-eight adult female moose were cap-

tured 61 times during the course of this study. Most captures occurred in February (n = 54) from a helicopter (n = 53). Nearly all ultrasonic rump fat measurements were recorded in February (n = 41) with the exception of 5 in early to mid-March. We did not attempt to distinguish rump fat depth between cows with and without calves-at-side in winter because of inconsistency in reporting presence of a calf during capture. Mean rump fat depth was not different among years ($f_{(2,43)}$ = 0.9, P = 0.399; Table 1). There were no differences between rump fat depth for pregnant cows observed with (x = 24.1 mm, SE = 2.4, n = 8) or without calves (x = 27.4 mm, SE = 1.3, n = 31) in the spring following capture (t = 1.18, df = 37, P = 0.246). Differences were observed in BCS among years ($f_{(2,51)}$ = 4.8, P = 0.012) and *post hoc* analyses indicated that BCS in 2005 were significantly higher than in either 2006 or 2007 (Table 1).

Moose (n = 59) were negative for antigens against *B. abortus* in all years and for *Leptospira*, infectious bovine rhinotracheitis virus, bovine viral diarrhea virus, parainfluenza-3 virus, and bovine respiratory syncytial virus in 2005 (n = 20). Winter tick loads were relatively low and averaged 2.8 ticks/moose with 55 of 59 moose hosting <10 ticks. No moose (n = 56) had evidence of ear mites and fluke eggs were not observed in any sample (n = 43). Fecal examinations (n = 44) indicated a low infection (≤12 eggs/g) of *Nematodirus spp*. in 13 moose and *Trichostrongylus spp*. in 2 moose.

Hematological, Serum Chemical, and Macroelement Analyses

There were no among-year differences in Hb (P = 0.053) or platelets (P = 0.104), but differences were found for PCV ($f_{(2,48)}$ = 9.5, P <0.005), MCHC ($f_{(2,48)}$ = 8.3, P <0.005), RBC ($f_{(2,48)}$ = 6.9, P = 0.002), and WBC ($f_{(2,48)}$ = 4.7, P = 0.013; Table 2). No consistent increasing or decreasing patterns were observed for PCV, MCHC, or RBC, but WBC exhibited a generally increasing trend with 2005 significantly lower than 2007. The percent composition of WBC did not differ among years for lymphocytes (P = 0.089), eosinophils (P = 0.353), or monocytes (P = 0.168), but differences were observed for neutrophils ($f_{(2,48)}$ = 4.7, P = 0.014), and *post hoc* analyses indicated that 2007 was significantly lower than 2005 and 2006 (Table 2).

For serum chemical analyses, there were no among-year differences for ALP (P = 0.149) and GGT (P = 0.339), but differences were found for ALB ($f_{(2,54)}$ = 19.0, P < 0.005), AST ($f_{(2,54)}$ = 10.3, P < 0.005), BUN ($f_{(2,54)}$ = 4.7, P < 0.005), CK ($f_{(2,53)}$ = 6.5, P = 0.003), globulins ($f_{(2,54)}$ = 23.6, P <0.005), glucose ($f_{(2,54)}$ = 12.5, P <0.005), LDH ($f_{(2,54)}$ = 47.1, P <0.005), and TSP ($f_{(2,54)}$ = 48.3, P < 0.005; Table 3). No consistent increasing or decreasing patterns were observed for ALB, AST, BUN, globulins, glucose, LDH, and TSP. However, CK values exhibited a generally increasing

Table 1. Count (n), mean (x) ± standard error (SE), and 95% confidence intervals (CI) for rump fat depth and body condition scores (BCS) by year for adult female moose captured in northwest Wyoming during winter 2005-2007.

Year	Parameter	n	x ± SE	95% CI[1]
2005	Rump fat (mm)	13	27.6 ± 3.5	19.9 - 35.3
	BCS	17	7.5 ± 0.3	6.9 - 8.2
2006	Rump fat (mm)	18	26.4 ± 1.3	23.7 - 29.0
	BCS	19	6.6 ± 0.2	6.1 - 7.0
2007	Rump fat (mm)	15	23.6 ± 1.3	20.8 - 26.5
	BCS	18	6.6 ± 0.2	6.1 - 7.0

[1]Upper and lower confidence interval.

Table 2. Mean ± standard deviation for hematological analyses of adult female moose captured in northwest Wyoming during winter 2005-2007.

Parameter[1] (units)	2005 (n = 19)	2006 (n = 16)	2007 (n = 16)
PCV (%)	54.7 ± 7.9	45.6 ± 4.5	49.7 ± 5.2
Hb (g/dl)	16.5 ± 2.1	15.6 ± 1.6	17.2 ± 1.7
MCHC (g/dl)	30.6 ± 4.8	34.2 ± 1.9	34.7 ± 2.0
RBC (x 10^6/µl)	7.9 ± 1.3	6.8 ± 0.6	7.3 ± 0.7
Total WBC (/µl)	5296.8 ± 1581.2	5967.5 ± 1466.2	6952.5 ± 1706.7
Lymphocytes (%)	56.1 ± 9.6	56.4 ± 9.9	63.7 ± 13.2
Neutrophils (%)	36.2 ± 8.7	37.3 ± 8.9	27.9 ± 11.2
Eosinophils (%)	4.4 ± 3.2	3.7 ± 2.9	5.4 ± 4.1
Monocytes (%)	3.3 ± 1.8	2.7 ± 1.1	2.4 ± 1.0
Platelets (x 10^3/µl)	189.4 ± 53.0	148.4 ± 58.5	177.8 ± 58.7

[1]PCV = packed cell volume; Hb = hemoglobin; MCHC = mean corpuscular hemoglobin concentration; RBC = red blood cell; WBC = white blood cell.

pattern with 2007 significantly higher than 2005 (Table 3).

Analyses of serum chemical parameters indicated among-year differences for all 3 macronutrients (Ca: $f_{(2,54)} = 35.7$, $P < 0.005$; Mg: $f_{(2,53)} = 16.1$, $P < 0.005$; P: $f_{(2,54)} = 4.93$, $P = 0.011$; Table 3), but no consistent increasing or decreasing trend was evident. Annual means of serum Ca exceeded the lower normal limit threshold for domestic ruminants (8.0 mg/dl) in 2006 and 2007, but were slightly below this level in 2005 (Table 3). When moose were compared individually, 18% (11 of 58) had Ca levels <8.0 mg/dl threshold, and 57% (33 of 58) were below the domestic ruminant deficiency threshold (4.5 mg/dl) for serum P;

Table 3. Mean ± standard deviation for serum chemical analyses of adult female moose captured in northwest Wyoming during winter 2005-2007.

Parameter[1] (units)	2005 (n = 20)	2006[2] (n = 18)	2007 (n = 17)
Albumin (g/dl)	2.9 ± 0.5	3.8 ± 0.5	3.4 ± 0.4
ALP (U/l)	255.9 ± 99.1	338.1 ± 151.1	297.3 ± 125.5
AST (U/l)	62.4 ± 17.5	87.1 ± 18.6	103.7 ± 42.5
BUN (mg/dl)	3.4 ± 1.0	5.0 ± 2.4	3.4 ± 1.9
Ca (mg/dl)	7.9 ± 1.2	10.2 ± 0.4	10.5 ± 0.9
CK (U/l)	111.8 ± 76.6	238.8 ± 175.6	328.9 ± 267.1
GGT (U/l)	10.2 ± 5.7	16.2 ± 6.2	15.5 ± 22.3
Globulins (g/dl)	3.3 ± 0.8	4.6 ± 1.0	5.1 ± 0.7
Glucose (mg/dl)	102.6 ± 20.3	79.7 ± 20.6	72.0 ± 18.8
LDH (U/l)	161.5 ± 37.8	275.2 ± 58.2	310.5 ± 53.3
Mg (mg/dl)	2.0 ± 0.1	2.4 ± 0.1	2.4 ± 0.1
P (mg/dl)	3.7 ± 0.2	4.7 ± 0.3	4.3 ± 0.2
TSP (g/dl)	6.1 ± 1.1	8.4 ± 0.8	8.5 ± 0.6

[1]ALP = alkaline phosphate; AST = aspartate aminotransferase; BUN = blood urea nitrogen; Ca = calcium; CK = creatine kinase; GGT = gamma-glutanyl transferase; LDH = lactate dehydrogenase; Mg = magnesium; P = phosphorous; TSP = total serum protein.

[2]ALP, CK, and Mg (n = 17).

annual means were below this level in 2005 and 2007 (Table 3). The annual means of serum Mg exceeded the lower normal limit threshold for domestic ruminants (1.8 mg/dl) in all years (Table 3); 12% (7 of 57) were below this level.

There was variation in the proportion of moose with PCV, Hb, TSP, Ca, and P values below those reported for Alaskan moose considered to be in average-above average condition (Table 4). Most moose fell below the average thresholds for Hb, Ca, and P; approximately 50% and 33% were below average for PCV and TSP, respectively. Mean Hb concentrations were lower in all years and PCV was lower in 2006 and 2007 (Table 2, Table 4). Serum levels of Ca and P were lower in all years and TSP was lower in 2005, but higher than the average threshold in 2006 and 2007 (Table 3, Table 4).

Of the 13 serum chemical parameters analyzed, 2 exhibited a marginally significant relationship with rump fat depth ($n = 43$ moose; $\alpha = 0.05$). Aspartate aminotransferase (r_s = -0.339, P = 0.041; Fig. 1) and LDH (r_s = -0.327, P = 0.049; Fig. 2) were both negatively correlated with depth of rump fat. The enzyme CK was partially correlated and negatively related to rump fat (r_s = -0.317, P = 0.057); however, when the single CK value >1000 U/l was removed, the direction of correlation reversed and the relationship was insignificant (r_s = 0.237, P = 0.130).

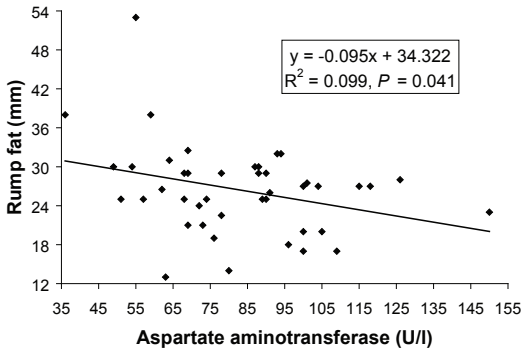

Fig. 1. Scatterplot describing the relationship between rump fat depth (mm) and aspartate aminotransferase (U/l) concentrations of captured adult female moose in northwest Wyoming, winter 2005-2007 (n = 43). The relationship was significant at the $\alpha = 0.05$ level, but became insignificant when Bonferroni corrections were applied ($\alpha = 0.004$).

When Bonferroni corrections were applied, the correlations observed between rump fat, AST, and LDH were insignificant. No significant relationship was observed between rump fat and any hematological parameter (n = 38 moose).

Serum and Hair Trace Mineral Analyses

Serum Cu, Fe, and Zn were detected in all moose (Table 5), whereas Mn and Mb had levels below the MDL and were undetected. There were no among-year differences in Cu (P = 0.329), but differences were found for Fe ($f_{(2,47)}$ = 3.79, P = 0.030) and Zn ($f_{(2,47)}$ = 25.1, P <0.005). No consistent increasing

Table 4. Total adult female moose sampled (n), range, and the proportion of the sample that was below the reference value for Alaskan moose considered to be in average-above average condition for 5 blood parameters used for condition assessment.

Parameter[1] (units)	n	Range	Reference[2]	Proportion below reference
PCV/HCT (%)	51	35.1 - 50.0	50	0.51
Hb (g/dl)	51	12.1 - 18.6	18.6	0.88
TSP (g/dl)	58	3.6 - 7.5	7.5	0.33
Ca (mg/dl)	58	5.2 - 10.4	10.4	0.81
P (mg/dl)	58	2.1 - 5.2	5.2	0.78

[1]PCV = packed cell volume; Hb = hemoglobin; TSP = total serum protein; Ca = calcium; P = phosphorous.

[2]Values for Alaskan moose in average-above average condition (Franzmann and LeResche 1978).

Table 5. Annual mean ± standard deviation, published deficiency levels, and the proportion of sampled adult female moose that were deficient in micro- and macronutrients analyzed in serum and hair from northwest Wyoming during winter 2005-2007. No published deficiency levels were reported for barium, chromium, and lead.

Element (units)	Sample type	Time 2005	2006	2007	Published deficiency levels (ppm)	Proportion below deficiency level
Copper (ppm)	Serum	0.51 ± 0.09	0.46 ± 0.14	0.45 ± 0.10	< 0.6[1,2]	0.84
	Hair	4.76 ± 0.72	4.63 ± 0.56	4.43 ± 0.65	< 6.7[2]	1.00
Iron (ppm)	Serum	2.78 ± 0.38	2.33 ± 0.74	2.32 ± 0.46	< 1.1[1]	0.02
	Hair	26.35 ± 16.70	19.12 ± 8.32	15.37 ± 6.54	≤ 40[2]	0.95
Zinc (ppm)	Serum	0.58 ± 0.13	1.42 ± 0.60	0.71 ± 0.09	< 1.0[1]	0.70
	Hair	82.64 ± 7.74	89.49 ± 3.52	89.86 ± 2.98	< 100[1]	1.00
Manganese (ppm)	Hair	1.09 ± 0.16	0.79 ± 0.08	1.00 ± 0.25	< 5.0[1]	1.00
Barium (ppm)	Hair	1.29 ± 0.74	1.79 ± 0.63	1.73 ± 0.64		
Chromium (ppm)	Hair	1.73 ± 0.55	1.39 ± 0.20	1.57 ± 0.29		
Lead (ppm)	Hair	0.17 ± 0.09	0.11 ± 0.06	0.26 ± 0.35		

[1]Deficiency level for cattle and sheep; Mn levels are indicative of slight deficiency (McDowell 2003).

[2]Deficiency level for cattle (Puls 1994).

or decreasing patterns were observed for the annual means of Fe and Zn. When compared to domestic ruminants, sampled moose were deficient in Cu during all years and deficient in Zn in 2005 and 2007 (Table 5). When examined individually, a high proportion of moose were deficient in Cu and Zn (Table 5); only in 2006 were moose (n = 15) above the Zn deficiency threshold. Annual means of serum Fe exceeded the 1.1 ppm threshold during all years; only 2% (1 of 50) of individual moose were below this level (Table 5).

Hair concentrations of As, Cd, Co, Hg, Mb, Ni, Se, Tl, V, and Sn were consistently below MDL, whereas all samples had detectable levels of Ba, Cr, Cu, Fe, Mn, Pb, and Zn (Table 5). There were no among-year differences in Cu (P = 0.279), Mn (P = 0.429), and Pb (P = 0.080); differences were found for Ba ($f_{(2,56)}$ = 3.34, P = 0.043), Cr ($f_{(2,56)}$ = 4.80, P = 0.012), Fe ($f_{(2,56)}$ = 4.52, P = 0.015), and Zn ($f_{(2,56)}$ = 11.80, P < 0.005). No consistent increasing or decreasing patterns were observed in concentrations of Ba, Cr, and Zn, but Fe

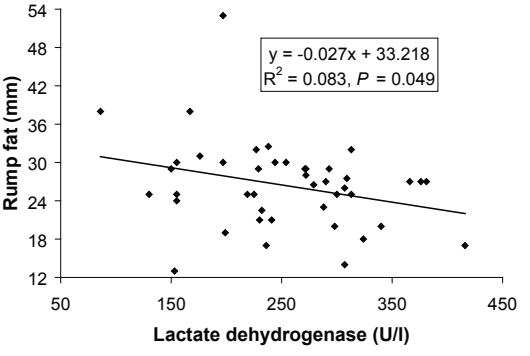

Fig. 2. Scatterplot describing the relationship between rump fat depth (mm) and lactate dehydrogenase (U/l) concentrations of captured adult female moose in northwest Wyoming, winter 2005-2007 (n = 43). The relationship was significant at the α = 0.05 level, but was insignificant when Bonferroni corrections were applied (α = 0.004).

concentrations showed a generally decreasing pattern; 2007 means were significantly lower than in 2005. Annual means for Cu, Fe, Zn, and Mn were below the deficiency thresholds for domestic ruminants in all years (Table 5). When examined individually, all moose were deficient in Cu, Zn, and Mn, and all but 3 moose were below the deficiency threshold for Fe (Table 5).

DISCUSSION

Blood Parameters and Rump Fat

Although PCV, Hb, TSP, Ca, and P have been used to evaluate habitat quality and the nutritional status of Alaskan moose (Franzmann and LeResche 1978), we, like Keech et al. (1998) with Alaskan moose, found none of these parameters were correlated with Shiras moose rump fat depth. Our results suggest that the serum enzymes AST and LDH may be good predictors of Shiras moose condition as indexed by ultrasonic rump fat measurements. Even though neither variable was significant when the Bonferroni correction was applied, they were significant at the $\alpha = 0.05$ level and the negative relationship between AST and rump fat is consistent with previous work with Alaskan moose . Keech et al. (1998) suggested that reduced levels of AST were indicative of moose that were in better physical condition which likely reduces their susceptibility to disease. Although this may be true, AST and LDH are indicators of muscle or organ damage generally associated with exertional myopathy (EM; Williams and Thorne 1996). Levels of AST for Shiras moose were not indicative of EM and were well below values reported for bighorn sheep that were stressed or subsequently developed EM (Kock et al. 1987). Additionally, levels of AST were well below normal values reported for moose (Haigh et al. 1977) which suggests that EM had little influence on these relationships.

The negative relationships that we observed between AST, LDH, and rump fat are consistent with increased utilization of body proteins from muscle and organ tissues as lipid reserves decline in lean animals. Cherel et al. (1992) observed a similar trend in which lean rats utilized greater amounts of muscle protein during phase II fasting (i.e., protein sparing) than did obese rats. While we observed a marginally significant relationship between two serum enzymes and rump fat depth, as with caribou (*Rangifer tarandus*; Messier et al. 1987), elk (Cook et al. 2001), and moose (Keech et al. 1998), we cannot identify a set of blood parameters in Shiras moose that accurately reflects nutritional status as an index of rump fat. Because not all managers have access to an ultrasound to evaluate moose condition, further evaluation of these relationships appears warranted since blood samples are more easily obtained.

Although rump fat depth should be interpreted with caution since we measured in a slightly different location than previous studies, our field measurements indicated that moose in the study area were in relatively good physical condition. Furthermore, the landmarks that were used to ensure measurements occurred in the same location on each moose were oftentimes difficult to locate, suggesting that most study animals carried high amounts of subcutaneous fat. When compared to rump fat of moose captured in early to mid-March in Alaska (Keech et al. 1998, Bertram and Vivion 2002, Boertje et al. 2007), this population displayed nearly 2X more rump fat. Although we were unable to compare rump fat for moose with and without calves-at-side during capture, other studies found that cow moose with greater amounts of rump fat were not tending calves (Testa and Adams 1998, Keech et al. 2000). Since calf recruitment has declined for approximately 20 years (Becker 2008), the high rump fat values may reflect fewer cows with calves. While rump fat may be a useful predictor of reproductive success within moose populations, it appears to be an insensitive index of fitness when compared across populations

(Boertje et al. 2007). Additionally, Heard et al. (1997) suggested that moose populations living in relatively harsh environments, or in areas with low forage quality or quantity, may have a higher fat-fertility threshold than moose populations living in milder climates with quality forage. Thus, our high rump fat values may indicate a population needing to maintain high fat levels to realize their optimal reproductive potential. Nonetheless, a larger sample size collected across multiple locations may provide researchers and managers with more accurate baselines of seasonal rump fat level and reproductive performance for moose in Wyoming. As with evaluations of elk condition (Cook et al. 2001), the thickness of specific muscles measured via ultrasonography could provide an additional index used with rump fat depth to provide a more accurate assessment of the physical condition (i.e., protein versus fat catabolism) of Shiras moose populations.

Although we are confident that most ultrasound measurements were recorded accurately, certain concerns were raised by other professionals sent images for their interpretation. We were able to validate our measurements on one adult female moose that was euthanized during capture and another that died within a month of capture; both had high amounts of subcutaneous fat. Nonetheless, it is possible that inconsistencies occurred because we had insufficient training and may have measured the wrong tissue layer for some moose, especially those with little fat reserves (Cook et al. 2007). Similarly, the difference in BCS between 2005 and other years likely resulted from inexperience in the application of this subjective method, as well as multiple individuals scoring moose in 2005. For consistency, one person most familiar with the scoring method palpated moose and provided the BCS scores in 2006 and 2007; this approach likely reduced variation in those years.

Moose from the study area appeared to be in marginal physical condition based on the 5 blood parameters (PCV, Hb, TSP, Ca, and P) considered as predictors of nutritional status of moose (Franzmann and LeResche 1978). This suggests that habitat conditions may be slightly suboptimal, but it is clear that conditions are not extreme. When compared to Alaskan moose considered in good-excellent condition (Franzmann and LeResche 1978), most adult female moose were below the reference values for PCV, Hb, Ca, and P and above the reference value for TSP. When these blood parameters were further compared to an expanding, highly productive population and one that was in poor condition from Alaska (i.e., populations on the extremes; Franzmann et al. 1987), moose from the study area fell in the middle. Because blood parameters vary across winters of differing severity (Ballard et al. 1996), are best used to identify populations at nutritional extremes (Franzmann at el. 1987), and are not always representative of other indices of physical condition (Keech et al. 1998), their efficacy in assessing condition of many populations is likely limited.

Micro- and Macronutrients

Adult female moose in the study area exhibited annual variation in nearly all micro- and macronutrients. These results suggest that the nutritional quality of moose browse exhibits similar annual variation. Indeed, researchers in Alaska and Sweden have reported high annual variation in the mineral content of moose browse (Oldemeyer et al. 1977, Ohlson and Staaland 2001). It has been suggested that a diversity of browse species can better meet the nutritional requirements of moose than a single, highly abundant species (Oldemeyer et al. 1977, Miquelle and Jordan 1979, Ohlson and Staaland 2001). Moose in the study area utilized low-elevation, riparian habitats dominated by large communities of willow intermixed with small stands of conifers and aspen during winter (Becker 2008), suggesting that willow composed a high proportion of the winter diet. If willows are deficient in certain

nutrients, moose that consume high quantities of willow may also be deficient in these elements. Direct analysis of forage quality is a more precise indicator of deficiency in most cases (McDowell 2003), thus future investigations may explore potential links between diet diversity and nutritional deficiencies on winter and summer ranges of Shiras moose.

Since moose acquire nutrients directly from the plants they consume (McDowell 2003), low concentrations of some minerals in serum and hair suggest nutritional limitations associated with moose habitat in the study area. Our results indicate that winter forage may have been limited in Cu, Zn, Mn, and P. Deficiencies in any nutrient are most likely to occur during winter when the availability and mineral content of forage is most limited (Kubota et al. 1970, Oldemeyer et al. 1977, Ohlson and Staaland 2001). Increased intra- and interspecific competition for limited winter forage (O'Hara et al. 2001) may exacerbate existing nutritional deficiencies due to overutilization of resources (Barboza et al. 2003). For example, overabundant free-ranging elk would remove preferred vegetation and reduce forage quality earlier in winter in willow-dominated, riparian range in the Buffalo Valley.

Moose may be highly susceptible to nutritional deficiencies (Murray et al. 2006), and although Cu, Zn, Mn, and P deficiencies are extremely difficult to diagnose in wild populations, the physiological imbalances that they may create could have considerable impact on the performance of the population, particularly the developing fetus and calf. While we cannot conclude that low or marginal Cu has been the primary cause of the recent moose decline, it remains a possible contributing factor because concentrations in serum and hair indicated a potential deficiency among moose in the study area. Most Cu is stored in the liver, but when levels are <20 μg/g, serum and hair become sensitive indicators of Cu deficiency among domestic ruminants (Combs 1987, Blakley et al. 1992, McDowell 2003). Copper is an essential nutrient for the developing fetus, and fetal demand of Cu greatly increases during the final trimester of pregnancy (Puls 1994, McArdle 1995, Rombach et al. 2003); the likelihood of reproductive failure presumably increases if maternal Cu is deficient (Hidiroglou and Knipfel 1981, McDowell 2003). Serum Cu levels in moose from the study population were similar to levels measured in Cu deficient elk that experienced reduced adult survival and poor recruitment (Gogan et al. 1989).

Although we did not observe faulty hoof keratinization associated with Cu deficiency, moose had reduced reproductive output (Becker 2008) similar to populations from the Kenai Peninsula, Alaska (Flynn et al. 1977), the north slope of Alaska (O'Hara et al. 2001), and Minnesota (Custer et al. 2004). However, low Cu levels alone were not responsible for the reduced reproductive success among pregnant moose in northwest Wyoming (Becker 2008). It may be that the cumulative effects of stressors (i.e., low quality forage, moderate physical condition, environmental conditions) near the third trimester of pregnancy combined with potential deficiencies in several other nutrients (i.e., Mn, Zn, P) created physiological imbalances (Frank et al. 1994) that compromised reproductive performance.

Concentrations of Mn in hair and Zn in serum and hair indicated a potential deficiency in the study area. All hair samples suggested a deficiency in these nutrients while approximately two-thirds of moose were serum Zn deficient. All moose that were above serum Zn deficiency thresholds were sampled in 2006; however, these higher levels were likely a result of sample contamination from incorrect collection procedures (Puls 1994). In domestic ruminants, clinical signs of Mn and Zn deficiencies include reduced reproductive performance and calf survival (Hidiroglou 1979, Hidiroglou and Knipfel 1981, McDowell 2003). To our knowledge, clinical signs of Mn

and Zn deficiencies have not been observed in wild moose populations. The reliability of using serum and hair to assess dietary intake of Mn and Zn is relatively low (Smart et al. 1981, Combs 1987, McDowell 2003), but the possibility remains that deficiencies occurred in the study population.

The low serum P observed in the sample population in 2005 and 2007 may have been partially due to the effect of capture. Although Franzmann and LeResche (1978) did not observe changes in serum P concentrations during their study, Karns and Crichton (1978) observed a decrease in P in caribou from the time of capture to release. Our capture techniques may have delayed sample collection in some moose causing a decrease in P concentration. Nonetheless, McDowell (2003) noted that P has to be consistently below the deficiency threshold to consider a population deficient. Since moose were not deficient all 3 years of the study, further investigation appears warranted.

Parasites and Disease

Insignificant loads of endoparasites in fecal samples and tick counts suggested a relatively low infestation of winter ticks in most of the study area. The low tick counts may have been due partially to inexperience in identifying the nymph stage which is common during February. However, patterns of hair discoloration and loss in March and April (Lankester and Samuel 1997, Samuel 2004) also suggest relatively low tick loads on moose from the northern part of the study area, whereas moose occupying winter ranges further south appear to carry higher tick loads. Field observations indicated that snow cover remained longer into spring on the northern winter ranges, but disappeared rapidly to the south. Snow cover during April adversely affects tick reproductive success (Drew and Samuel 1986) whereas warm, dry spring conditions may enhance tick abundance the following autumn (Samuel 2004).

The 6 disease antigens did not appear to play a large role in the dynamics of moose in northwest Wyoming. Brucellosis seroprevalence in elk was 12.5% in the Buffalo Valley (Barbknecht 2008), thus there was potential for transmission on winter range. However, experimental studies of brucellosis in moose indicate that they may be a dead-end host for the disease because infection leads to rapid mortality (Forbes et al. 1996). Deaths associated with brucellosis infection have not been observed among moose in the Greater Yellowstone Ecosystem (Cook and Rhyan 2003), but due to the rapid progression of the disease, clinical symptoms of infection may not be observed prior to death.

ACKNOWLEDGEMENTS

Funding was provided by Teton County Conservation District, Wyoming Animal Damage Management Board, Wyoming Department of Transportation, Wyoming Game and Fish Department, and Wyoming Governor's Big Game License Coalition/Wildlife Heritage Foundation of Wyoming. We thank Bridger-Teton National Forest, Grand Teton National Park, Wyoming Game and Fish Department, and Yellowstone National Park for logistical support and our pilots G. Lust (Mountain Air Research [retired]), D. Savage (Savage Air Services), and D. Stinson (Sky Aviation) for their expertise in the air. We wish to acknowledge the efforts of numerous personnel who assisted with field, office, and logistical support, especially C. Anderson, D. Brimeyer, S. Dewey, T. Fuchs, H. Harlow, W. Hubert, S. Kilpatrick, T. Kreeger, F. Lindzey, W. Long, S. Smith, and T. Thurow. We also thank W. Edwards, T. Cornish, M. Raisbeck, R. Siemion, and others from the Wyoming State Veterinary Laboratory for diagnostic analyses and guidance. T. Schuff provided assistance with ultrasonography and C. C. Schwartz was always available for thought-provoking discussions about animal nutrition. A. E. Barbknecht, E. J. Wald, and others have

improved this manuscript through their constructive reviews.

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