EXTENDING BODY CONDITION SCORING BEYOND MEASUREABLE RUMP FAT TO ESTIMATE FULL RANGE OF NUTRITIONAL CONDITION FOR MOOSE

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ABSTRACT: Moose (*Alces alces*) populations along the southern extent of their range are largely declining, and there is growing evidence that nutritional condition — which influences several vital rates – is a contributing factor. Moose body condition can presently be estimated only when there is measurable subcutaneous rump fat, which equates to animals with >6% ingesta-free body fat (IFBFat). There is need for a technique to allow body fat estimation of animals in poorer body condition (i.e., <6% body fat). We advance current methods for moose, following those used and validated with other ungulate species, by establishing a moose-specific body condition score (BCS) that can be used to estimate IFBFat in the lower range of condition. Our modified BCS was related strongly ($r^2 = 0.89$) to IFBFat estimates based on measurable rump fat. By extending the predicted relationship to individuals without measurable fat, the BCS equated severe emaciation with 0.67% IFBFat, supporting the accuracy of the method. The lower end of nutritional condition is important for identifying relationships involving life-history characteristics because most state-dependent changes occur at lower levels of condition. Therefore, until the BCS can be validated with moose carcasses, we believe our method to estimate body fat across the full range of condition should yield better understanding of the drivers underlying declining moose populations.

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Key words: *Alces alces*, ingesta-free body fat, body condition score, moose, nutrition, ultrasound, ultrasonography, validation

The nutritional condition (i.e., percent ingesta-free body fat [IFBFat]) of an individual integrates nutrient gains and losses as it reflects previous life-history and habitat quality (Cook et al. 2007, Monteith et al. 2014). Indeed, nutritional condition forms the foundation for life-history of individuals and affects nearly every demographic component of a population (Parker et al. 2009, Monteith et al. 2014, Stephenson et al. 2020). Across moose (*Alces alces*) distribution, nutritional limitation underpins body size, reproductive success, and population growth rate (Murray et al. 2006, Monteith et al. 2015, Hoy et al. 2017, Schrempp et al. 2019, Jesmer et al. 2021). Several nutritional metrics, including iron levels and fat content, were related to probability of pregnancy in western Montana (Newby and DeCesare 2020). In Utah, production and recruitment of young increased linearly with rump fat measurements (Ruprecht et al. 2016). Similarly, moose in Minnesota were less likely to be pregnant when malnutrition was indicated by bone marrow fat, blood indices, and rump fat measurements (Murray et al. 2006, DelGiudice et al. 2011). Further, in Wyoming, body fat was a strong predictor of pregnancy, parturition, survival, and therefore population growth rate (i.e., lambda), thus linking nutritional condition to demography (Oates et al. 2021). The role of nutrition in the life-history of moose necessitates a reliable and reproducible metric for determining nutritional condition of individuals and populations to help identify factors affecting population demograhics and enhance conservation and management efforts for this species.

Methods used to assess nutritional condition of ungulates employ both post-mortem and *in vivo* indices, including marrow fat (Cheatum 1949), kidney fat (Riney 1955), back fat (Anderson et al. 1972), visual examination of organ fat (Kistener et al. 1980), and physical descriptions (Franzmann 1977). *In vivo* methods are preferable because they allow for repeated sampling of individuals which yields potential to connect nutritional condition to life-history and environmental characteristics while avoiding animal sacrifice. When coupled with a body condition score (BCS) acquired via palpation, thickness of rump fat measured via ultrasonography has become the gold standard to accurately estimate total body fat *in vivo* for ungulates (Cook et al. 2001b, 2021a). Predictive equations following a standardized approach have been developed and calibrated for mule deer (*Odocoileus hemionus*; Stephenson et al. 2002, Cook et al. 2007), elk (*Cervus canadensis*; Cook et al. 2001a, 2001b), bighorn sheep (*Ovis canadensis*; Stephenson et al. 2020), and caribou (*Rangifer tarandus*; Cook et al. 2021a).

In moose, predictive equations for estimating percent IFBFat based on ultrasonography measurements of maximum depth of rump fat are highly related (r^2 = 0.96; Stephenson et al. 1998), but ultrasonography alone does not allow estimation across the full range of body condition (<1 mm rump fat). As in other North American cervids, subcutaneous rump fat is depleted when moose reach 5.63% IFBFat (Cook et al. 2010, 2021a); however, the BCS derived from palpation to estimate IFBFat below that threshold has not been developed for moose. Consequently, quantifying relationships with nutritional condition in moose is hampered by a lack of resolution at lower levels of IFBFat when fitness or behavioral consequences should be most evident (Ruprecht et al. 2016, Newby and DeCesare 2020). Efforts to address this gap in knowledge do exist, including a body scoring system which delineates individual moose by describing appearance, boniness, and gait (Franzmann 1977); however, the scores of live-captured moose using this technique had a statistically significant but weak relationship with IFBFat determined via ultrasonography (r^2 = 0.34; DelGiudice et al. 2011). Similarly, while scoring systems validated for other cervids have been applied to moose (Cook et al. 2021b), a species-specific BCS would be more appropriate given the morphological differences among species. Validating the relationship between BCS and rump fat for moose would be ideal given its usefulness in other species (Cook et al. 2001a, 2007, 2010); however, challenges of sacrificing a sufficient number of moose to determine body composition via homogenization and chemical analysis (e.g., Stephenson et al. 1998, Cook et al. 2001a) have precluded its development.

In lieu of validating a BCS for moose via sacrifice, we used an ad hoc approach to develop a BCS for estimating IFBFat of moose with no measurable rump fat. Given the established relationship between BCS and IFBFat developed with other ungulates (Cook et al. 2001a, 2007, 2021a; Stephenson et al. 2002, 2020), we developed a BCS for moose. For moose with measurable rump fat, we then regressed their IFBFat estimates and BCS to develop a predictive equation (Stephenson et al. 1998). We subsequently extended this relationship to include moose below the threshold of measurable rump fat to estimate IFBFat across the full range of nutritional condition.

STUDY AREA

We studied moose (*A. a. shirasi*) from the Sublette herd in the Green River Basin of northwest Wyoming, USA (42.8653˚N, 110.0708˚W) in February 2011, 2012, and 2013 (see Jesmer et al. 2017, 2021, Oates et al. 2021). Winters were characterized by mean temperatures below 18°C and deep snow (annual mean snowfall 160 cm). Riparian areas used by moose were dominated by Booth's (*Salix boothii*) and Geyer's willow (*S. geyeriana*). Surrounding areas consisted of either mixed coniferous forest (*Abies lasiocarpa*, *Pinus contorta, Picea engelmannii*, *Pseudotsuga menziesii*), aspen forest (*Populus tremuloides*), mixed conifer-aspen forest, or sagebrush (*Artemisia* spp.) steppe. This population of moose was considered stable for the duration of our study (Wyoming Game and Fish Department, unpublished data).

METHODS

We captured 48 adult female moose via helicopter net-gunning on 13–15 February 2012. Moose were blindfolded, hobbled, and restrained in a sternal recumbent position on their left side. The right, incisiform canine was removed following the methods of Swift et al. (2002), and age was determined via cementum annuli (Matson's Laboratory, Milltown, Montana, USA). We measured body length from the dorsal margin of the planum nasale to the tip of the tail following the contour of the body using a cloth tape, and measured chest girth from the middle of the sternum to the spinous process while maintaining the tape immediately posterior to the scapula and perpendicular to the spine. Subsequently, we predicted body weight using the relationship between body length and chest girth (Hundertmark and Schwartz 1998).

To assess nutritional condition, we measured the maximum depth of rump fat (MAXFAT; Stephenson et al. 1998) using a Bantam II portable ultrasound device (E.I. Medical Imaging, Loveland, Colorado, USA) with a 5-MHz linear-array transducer (Stephenson et al. 1998). We accompanied ultrasound with palpation and developed a modified BCS (Appendix A), analogous to that validated for elk (Cook et al. 2001a) and mule deer (Cook et al. 2007) and highly correlated with percent IFBFat ($r^2 \geq 0.86$). The University of Wyoming Institutional Animal Care and Use Committee approved capture and handling procedures (protocol #20140124JG00057).

Our initial set of analyses used linear regression to establish the relationship between IFBFat and BCS. We calculated percent IFBFat of moose with measurable rump fat using established equations (Stephenson et al. 1998), with scaled estimates to correct MAXFAT to body size (Cook et al. 2010). Previous MAXFAT analyses considered animals with minimal rump fat (<3 mm) to have no measurable fat because these measurements represent the fascia thickness (Cook et al. 2001a, 2007). Nevertheless, our use of conduction ultrasonography and high-resolution equipment allowed us to avoid inclusion of fascia thickness as part of the rump fat measurement. We therefore distinguished true MAXFAT measurements from fascia and included those individuals with MAXFAT >0 mm and <3 mm as animals with measurable rump fat. We excluded moose with no measurable rump fat (MAXFAT = 0) from our regression of IFBFat and BCS because our aim was to use the derived relationship to predict the IFBFat of these individuals.

We used linear regression to establish the relationship between BCS and percent IFBFat (Fig. 1) within the known range of IFBFat (>5.63%; animals with measurable rump fat). We then extended the relationship between BCS and values of IFBFat below 5.63%, assuming the linear relationship between BCS and IFBFat would hold (Stephenson et al. 2020). During capture, we handled 1 moose that was in extremely poor condition, characteristic of an animal suffering from severe malnutrition, and which ultimately died later that winter. The mortality occurred in early spring (29 April), which was typical of malnourished moose in the region as they were not exposed to predators. Based on previous experience with quantifying nutritional condition of ungulates, we expected this individual to have minimal remaining IFBFat (i.e., <1%). We used the estimates of IFBFat from the regression equation as a test case for our derived relationship, anticipating that our scoring system and regression should accurately estimate a starving moose to have little to no body fat.

RESULTS

Estimates (±SE) of age ranged from 3 to 10 years old (4.5 ± 0.3 years); only 4 of 48 individuals were >7 years old. Average body and metatarsus length were 270.1 ± 1.8 cm (range: 223–290 cm) and 56.5 ± 0.2 cm (range: 52–60 cm), respectively. Estimated body weight ranged from 244 kg to 419 kg, averaging 367.8 ± 4.8 kg. The MAXFAT measurements averaged 0.61 ± 0.01 cm, ranging from 0 to 2.0 cm.

There was a strong linear relationship between BCS and IFBFat for animals with measurable subcutaneous rump fat (r^2 = 0.89, n = 32; Fig. 1). Extending the linear relationship to include moose with a BCS but without measurable rump fat yielded none with IFBFat >6.0%. All individuals with BCS ≤2.75 were predicted to have no measurable rump fat, and conversely, all individuals with measurable rump fat had BCS > 2.75. The IFBFat estimate was 5.48% (95% CI: 5.15−5.80%) for individuals with BCS of 2.75 which was similar to thresholds where rump fat is depleted (5.8%, Stephenson et al. 1998; 5.63%, Cook et al. 2010). The predicted IFBFat for the individual in poor condition (presumed <1% IFBFat) was 0.67%. The population average of IFBFat was 6.42 ± 0.34% (range: 0.67–10.57%, n = 32).

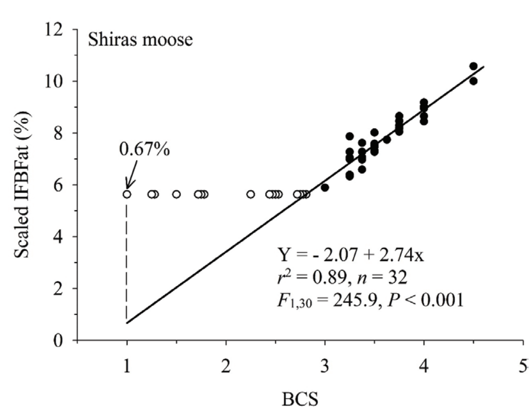

Fig. 1. Ingesta-free body fat (IFBFat) relative to body condition score (BCS) of adult female Shiras moose during mid-February 2012, Sublette County, western Wyoming, USA. Solid circles represent individuals with measurable subcutaneous rump fat and open circles represent individuals without measurable rump fat.

DISCUSSION

Poor nutritional condition underlies moose decline at the southern extent of their range (Murray et al. 2006, DelGiudice et al. 2011, Vartanian 2011), thereby calling for adequate tools to monitor their nutritional condition (Jesmer et al. 2017, 2021). We established a body condition scoring system to estimate IFBFat in moose (Appendix A) with depleted subcutaneous rump fat using BCS systems validated for other species as a foundation (Cook et al. 2001a, 2007, 2021a, Stephenson et al. 2020). We derived a linear relationship between our scoring system (BCS) and IFBFat using moose where IFBFat could be calculated with measurable MAXFAT (Stephenson et al. 1998). If our BCS scoring system was reliable, we expected that moose without measurable rump fat would have scores that corresponded with IFBFat levels below that detectable via ultrasound. These predictions were consistent with our findings; all moose without measurable rump fat were predicted to have <5.63% IFBFat. Further, the derived relationship predicted that a severely malnourished moose had <1% IFBFat. Until validation is possible via chemical analyses from animal carcasses, our equation to estimate IFBFat for moose without measurable rump fat should provide meaningful inference when nutritional limitation affects moose populations. Indeed, following our reported method herein, IFBFat was related strongly to pregnancy, overwinter adult survival, parturition, and ultimately, was a strong predictor of lambda in the same population (Oates et al. 2021).

By combining a validated equation for moose with measurable rump fat with a modified BCS, our approach extends the utility of existing methods to quantify nutritional condition of moose. Although an established scoring method (Franzmann 1977) identified a relationship between moose condition and pregnancy status (Testa and Adams 1998), it explained only a portion of the variation in IFBFat (r^2 = 0.34; DelGiudice et al. 2011). With our system, BCS scores were highly correlated with IFBFat (r^2 = 0.89, Fig. 1), and were comparable to BCS validated in elk (r^2 = 0.86, Cook et al. 2001a), mule deer (r^2 = 0.88, Cook et al. 2007), and bighorn sheep (r^2 = 0.77, Stephenson et al. 2020). Accordingly, our BCS system represents nutritional condition more accurately than previous scoring methods in moose, and it is commensurable to BCS systems used extensively in other ungulate species to assess fat reserves of animals in poor condition (Monteith et al. 2013, Long et al. 2014, Proffitt et al. 2021).

The lower end of nutritional condition, where fat reserves are depleted, is often the threshold beyond which animals face tradeoffs among nutritional reserves, reproduction, and survival. Moose can survive milder winters with body fat <5.63%, but pregnancy rate (Newby and DeCesare 2020, Jesmer et al. 2021, Oates et al. 2021) and survival probability decline (Oates et al. 2021) below this threshold. Thus, the point at which animals have depleted subcutaneous fat reserves is critical for drawing connections between life-history and nutrition. Relationships between life-history and fat reserves are likely to be overlooked without measurement at the lowest extent of nutritional condition. Indeed, changes in probability of pregnancy, parturition, and overwinter survival of adults occurred when IFBFat was <6% (Oates et al. 2021), or below the detection range of measurable rump fat. Our BCS for moose provided broader characterization of nutritional condition, particularly for individuals at the lowest extent of nutritional condition. We note the importance of adequate training on numerous animals (often >60 but dependent upon user adeptness) across a range of nutritional condition (Cook et al. 2021a) to accurately assess condition using a BCS. The BCS technique, when properly used, aids in identifying factors limiting population growth while linking behavioral and ecological characteristics to nutritional condition. Accurate assessment of nutritional condition is critical to identify stressors and sources of depressed productivity and survival associated with declining moose populations, and consequently, management options to enhance population performance.

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APPENDIX

Appendix A. Shiras Moose Body Condition Score

Score	Sacro-Sciatic Ligament	Base of Tail[1]	Caudal Vertebrae[2]	Sacrum
7	Ligament covered in fat	Indiscernible	Nearly indiscernible, w/ much fat	Not discernible
6	Ligament virtually indiscernible	Nearly indiscernible	Barely discernible, w/ much fat	Not readily discernible
5	Ligament discernible, fat evident	Barely discernible	Barely discernible, w/ fat	Barely discernible
4.25	Ligament discernible, some fat	Discernible, fat evident	Discernible, w/ fat	Barely discernible
3.75	Ligament discernible	Vertebrae rounded	Discernible, but fleshed w/ some fat	Rounded, barely discernible
3.25	Can pinch 0.5” w/o flesh covering	Vertebrae discernible, rounded	Individually discernible, but fleshed	Discernible ¼ way to tail
2.75	**Can pinch 1.0” w/o flesh covering**	**Vertebrae discernible, rounded**	**Individually discernible**	**Rounded, discernible**
2.5	Can pinch 1.25” w/o flesh covering	Vertebrae clearly discernible	Skeletal, but rounded	Rounded, discernible
2.25	Can pinch 1.5” w/o flesh covering	Vertebrae clearly discernible	Skeletal, but rounded	Rounded, prominent
2	Can pinch 1.75” w/o flesh covering	Vertebrae prominent and concave	Skeletal, w/ gaps	Rounded, prominent
1.75	Can pinch 2.0” w/o flesh covering	Vertebrae prominent and concave	Skeletal, w/ gaps	Rounded, prominent
1.5	Can pinch 2.25” w/o flesh covering	Vertebrae prominent and concave	Skeletal, w/ gaps	Skeletal, ≥0.5” protrusion
1.25	Can pinch 2.5” w/o flesh covering	Vertebrae sharp and concave	Skeletal, sharp w/ gaps	Skeletal, ≥0.5” protrusion
1	Can pinch ≥2.75” w/o flesh covering	Vertebrae sharp and concave	Skeletal, sharp w/ gaps	Skeletal, ≥1” protrusion

Last modified by K. L. Monteith in 2022.
Note: BCS 2.75–3.0 = subcutaneous fat depletion point.
We emphasize the importance of proper and repeated training to establish competency in assessing nutritional condition (Cook et al. 2021a).
[1] Caudal Vertebrae 2–3.
[2] Caudal Vertebrae 6–7.