Research Article

Validating Predictive Models of Nutritional Condition for Mule Deer

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ABSTRACT We developed new, and validated existing, indices of nutritional condition for live and dead mule deer (*Odocoileus hemionus*). Live animal indices included a body condition score (BCS), thickness of subcutaneous fat and selected muscles using ultrasonography, and body mass. Dead animal indices included femur, metatarsal, and mandible marrow fat, 3 kidney fat indices, and 2 carcass scoring methods. We used 21 female deer and 4 castrates (1–11 yr old) varying widely in nutritional condition (2–28% ingesta-free body fat). Deer were euthanized and homogenized for chemical analysis of fat, protein, water, and ash content. Estimates of fat and gross energy (GE) were regressed against each condition indicator using regression. Subcutaneous fat thickness, a rump BCS, and rLIVINDEX (an arithmetic combination of subcutaneous fat thickness and the rump BCS) were most related to condition for live animals ($r^2 \geq 0.87$, $P < 0.001$) whereas the Kistner score and kidney fat were most related to fat and GE for dead animals ($r^2 \geq 0.77$, $P < 0.001$). We also evaluated range of usefulness and sensitivity to small changes in body condition for all models. In general, indices with moderate or highly curvilinear statistical relations to body fat or those based on only one fat depot or a small number of ranking scores will have limitations in their use. Our results identify robust tools for a variety of research and monitoring designs useful for evaluating nutrition's effect on mule deer populations. (JOURNAL OF WILDLIFE MANAGEMENT 71(6):1934–1943; 2007)

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Mule deer populations (*Odocoileus hemionus*) have been declining in many of their historic ranges in the western United States (Fuller 1998, Gill et al. 2001, Mackie et al. 1998, Oregon Department of Fish and Wildlife 2003, Wasley 2004). Although reasons for these declines are unclear, declining nutrition, as a direct or indirect result of habitat change or loss, has been hypothesized as one of several possible causes (Bartmann 1984; Peek et al. 2001, 2002). Nutritional condition estimates are critical for understanding the impacts of habitat alteration or loss because they integrate the separate effects of nutritional adequacy of their environment with their nutrient demands (i.e., cumulative energy balance). Also, nutritional condition strongly influences reproductive success and survival probability (Verme 1969, Verme and Ullrey 1984, Cook et al. 2004).

Estimating nutritional condition requires practical and reliable techniques for routine monitoring and research. To date, a variety of nutritional condition techniques have been evaluated for moose (*Alces alces*; Stephenson et al. 1998), elk (*Cervus elaphus*; Cook et al. 2001*a*), and mule deer (Stephenson et al. 2002). However, Stephenson et al.'s (2002) mule deer models were developed using animals providing a limited range of body condition, and excluded techniques for measuring body condition useful for live animals with <6% body fat. Here, we evaluate a greater variety of approaches for evaluating nutritional condition in ungulates over a greater range of condition for mule deer than did Stephenson et al. (2002).

Live animal indices included a rump body condition score (rumpBCS; Wright and Russell 1984, Gerhart et al. 1996, Cook et al. 2001*a*), thickness of subcutaneous fat and selected muscles using ultrasonography (Bullock et al. 1991, Stephenson et al. 1998, Cook et al. 2001*a*), and body mass (Harder and Kirkpatrick 1994, Jiang and Hudson 1994). Dead animal indices included femur (Bubenik 1982, Mech and DelGiudice 1985, Depperschmidt et al. 1987), metatarsal (Davis et al. 1987, Marquez and Coblentz 1987), and mandible marrow fat (Ballard et al. 1981, Davis et al. 1987, Okarma 1989), 3 kidney fat indices (Riney 1955, Harder and Kirkpatrick 1994, Anderson et al. 1990), and 2 carcass scoring methods (Kistner et al. 1980, Lanka and Emmerich 1996). We excluded nutrition-sensitive rate variables such as serum, urine, and fecal chemistry (Harder and Kirkpatric 1994) because they are insensitive to animal states (e.g., body fat levels; Saltz and White 1991; Cook et al. 2001*a*, *b*). We assessed the relationship between each index and the percentage composition of body fat to develop models to predict nutritional condition. We also identified biological relationships that demonstrate the levels of condition to which the models apply and analyzed the sensitivity of each index to variations in nutritional condition.

STUDY AREA

We acquired 21 captive and wild females ranging in age from 1 year to 11 years old and 4 castrated captive males

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ranging in age from 1 year to 8 years old. Eastern Oregon Agriculture Research Center maintained the captive, castrated males and 3 captive females in 1-ha pens in Union, Oregon, USA. We maintained an additional captive female in 3-ha pens at the Wild Ungulate Facility at Washington State University, Pullman, Washington, USA. We fed captive animals an ad libitum diet of grain–alfalfa herbivore pellet (3.1% nitrogen and 30% neutral detergent fiber), alfalfa or timothy hay, and trace minerals at the time of processing (Dec 2002). We also acquired 15 wild females near Seven Bays in Northeast Washington from a suburban thinning program. We processed these animals February 2003, 2004 ($n = 8$) or December 2003 ($n = 7$). We obtained the final 2 females from a wild population near Bishop, California, USA, which we processed March 2003. Eight of the wild-caught females were gravid at the time of processing, whereas all of the hand-reared animals were nongravid.

METHODS

Data Collection and Animal Processing

We conducted this research in accordance with approved animal welfare protocol (Washington State University Institutional Animal Care and Use Committee Protocol No. 3131). At the time of processing, we anesthetized all hand-reared animals with 70–100 mg of xylazine hydrochloride, administered intramuscularly. Professional shooters shot females from Seven Bays on site in the neck using high-velocity 0.224-caliber rifles. We captured the remaining females via helicopter and then euthanized them immediately via a blow to the cranium.

We collected all live-animal measurements while deer were anesthetized or immediately following death. We used a body condition scoring (BCS) modified from one validated for elk (Cook 2000; Cook et al. 2001*a*, *b*). Modifications included altering the scoring criteria for a smaller-bodied animal, changing the scoring scale to 0–6 (vs. 1–5) to include the wider range of condition found in our deer, and limiting rankings to the rump for the final score. We also calculated a body reserve index (BRI = rumpBCS × body mass) following Gerhart et al. (1996). We measured subcutaneous rump fat thickness (MAXFAT) using ultrasonography (Stephenson et al. 1998; Cook et al. 2001*a*, *b*). We also determined scapula muscle (infraspinatus + scapular deltoid) thickness taken at the midpoint and 2.5 cm posterior to the scapular spine, and longissimus dorsi muscle thickness taken between the twelfth and thirteenth ribs adjacent to the backbone (see Herring et al. 1995).

After we collected live-animal indices, we euthanized the hand-reared animals via jugular injection of sodium pentobarbital. We hung, eviscerated, and weighed each deer. We then visually scored carcass fat, musculature, and visceral fat via the Kistner score (Kistner et al. 1980) and the Wyoming Index (Lanka and Emmerich 1996); both are visual scores originally developed for deer (*Odocoileus* spp.). The Wyoming Index is based on presence or absence of fat at the rump, stifle, and withers area (Lanka and Emmerich 1996). The Kistner system requires scoring based on 1) fat in indicator depot sites (cardiac, omental, perirenal, and subcutaneous areas); 2) the condition of the skeletal muscle mass; and 3) scoring in increments of 5 from 0 to 15 (Kistner et al. 1980). As with elk (Cook et al. 2001*a*), we found deer with fat levels around some internal organs (i.e., cardiac and perirenal areas) beyond the range of the original score. Thus, we modified the Kistner Score by increasing the scoring range from 0 to 20 for these organs, by removing the muscle mass evaluation because of its subjectivity, and by scoring in increments of one point. In addition, we assumed it would often be impractical to collect all 7 components of the Kistner score in a field setting and, thus, evaluated 2 subset scores. One subset was the sum of the heart, pericardium, and kidney scores and the second subset was the sum of the pericardium and kidney scores.

We split each deer in half lengthwise with hide and hair. We sectioned one-half of the carcass which we stored at –20° C and later homogenized to determine body composition. We collected the middle third of the femur, the mandible, and the metatarsal for bone marrow analysis (ovendry method; Neiland 1970) from the remaining half carcass. We used the first incisor to estimate age to the nearest year by examination of annuli (Hamlin et al. 2000; Matson's Laboratory, Milltown, MT).

We weighed the heart, pericardium, and kidneys with all attached fat. We trimmed peri-renal fat following Riney (1955), and weighed the kidneys, remaining fat, and trimmed fat. We calculated kidney fat indices (KFI) based on total fat mass and trimmed fat mass. For all analyses, we calculated KFIs separately for each kidney and used the average (Anderson et al. 1972).

We reweighed half carcasses and visceral masses immediately before grinding to account for water loss, and homogenized them in a whole-body grinder (Autio 801 B with a Falk 50 horsepower grinder; Autio Company, Astoria, OR) either at University of California (Davis) or Colorado State University. We ground carcass samples 3 times through a 2.5-cm screen and once with a 6-mm plate opening. We ground viscera twice through a 6-mm screen. We collected samples of the ground tissues (approx. 2.0 kg of the carcass and approx. 1.0 kg of the viscera) and stored them frozen until chemical analysis.

Chemical Analysis

We freeze-dried carcass and viscera samples to a constant weight and rehomogenized them in a Wiley grinder through a 1-mm screen with dry ice. We determined crude protein by the Kjeldahl procedure (Association of Official Agricultural Chemists 1980), percent fat by ether extract (Association of Official Agricultural Chemists 1965), and total ash by combustion for >2 hours at 500° C (Association of Official Agricultural Chemists 1960). We combined carcass and viscera compositions according to their relative mass to estimate ingesta-free composition of the whole body. We calculated gross energy (GE in Mcal/kg; Robbins 1993) by:

$$GE = [(9.11 \times \%fat) + (5.65 \times \%protein)]/100$$

We calculated fat-free, ingesta-free lean body mass by subtracting total fat (kg) from the ingesta-free body mass. We expressed water, protein, and ash as percentages of lean body mass.

Statistical Analysis

We first linearly transformed data when necessary (kidney fat indices, marrow indices, Kistner scores, MAXFAT). Second, we created 2 single-variable indices (rLIVINDEX and CONINDEX) from arithmetic combinations of 2 indices with different ranges of predictive ability. For CONINDEX, we combined femur marrow fat and KFI such that 1) when KFI $\geq$ 20, CONINDEX = (KFI $-$ 20) + femur marrow fat and 2) when KFI <20, CONINDEX = femur marrow fat as described by Connolly (1981). We calculated rLIVINDEX following Cook et al. (2001*a*) by combining rumpBCS and MAXFAT such that 1) when MAXFAT $\geq$ 0.2 cm, rLIVINDEX = (MAXFAT $-$ 0.2) + rumpBCS and 2) when MAXFAT < 0.2 cm, rLIVINDEX = rumpBCS (0.2 cm represents the point on deer where measurements correspond to fascia thickness rather than fat layer thickness).

Our initial set of analyses included regressions of individual indices with ingesta-free body fat and gross energy, producing equations and coefficients of determination for each index. For MAXFAT, we excluded all animals with <0.2 cm of rump fat from the regression analysis. In addition, because many animals in this study had no measurable rump fat, we included MAXFAT data from Stephenson et al. (2002; n = 9 ad F) to provide a larger sample size.

To address some criticisms of past studies (see Robbins 1983, Hobbs 1987, Cederlund et al. 1989, Harder and Kirkpatrick 1994), we analyzed each index using: 1) a range-of-usefulness evaluation to identify the range of condition to which the models apply and 2) an analysis of model sensitivity to test variation in the index relative to variation in the dependent variable. Range of usefulness refers to the range of nutritional condition over which each index is most accurate and reflects the specific form (e.g., linear, nonlinear, asymptotic, or truncated) of the index-condition relation. For example, some indices are useful only for animals in relatively poor condition, whereas others are useful for animals in relatively good condition (e.g., Cook et al. 2001*b*). To compare the range of usefulness among indices, we graphed levels of fat with a depletion ratio of each index (calculated using untransformed data as described by Cook et al. 2001*b*). This approach standardizes the depletion ratios across indices, with 1 being the highest value attained for that particular index for the range of condition found in our study (no depletion) and 0 being the lowest value (complete depletion). We then compared differences in depletion patterns among indices graphically.

Next, we compared variation associated with the indices relative to variation in the dependent variable (% fat). We wanted to determine if the predicted models generated from animals with a wide range of condition would still accurately assess condition if restricted to condition ranges typically found within seasons in wild deer herds (see Hobbs 1987). We estimated within-season range of fat levels of wild deer to be 7 percentage points based upon condition data collected during December (2000–2004) and late March (2000–2004) from 7 deer herds in eastern Washington (W. L. Myers, Washington Department of Fish and Wildlife, unpublished data). We randomly selected 26 subsets from our deer data, each with a 7 percentage-point range of body fat, and regressed percent fat on the index for each subset of data. We based model performance on the average coefficient of determination of the 26 regressions and the percentage of the regressions that were significant ($P \leq$ 0.05).

RESULTS

Total body fat of the ingesta-free body (IFBF) ranged from 2.6% to 19.2% in the females and from 19.2% to 27.6% in the castrated males; GE ranged from 1.51 Mcal/kg to 2.88 Mcal/kg in the females and from 2.97 Mcal/kg to 3.67 Mcal/kg in the castrated males; and protein ranged from 19.3% to 23.1% in the females and from 19.2% to 21.5% in the castrated males. Live mass ranged from 48.4 kg to 70.6 kg in the females and from 74.0 kg to 85.0 kg in the castrated males.

Percent body fat was linearly related to GE (Fat% = 11.616 $\times$ GE $-$ 14.541, $r^2 = 0.99$, $P \leq 0.001$) and percent water (Fat% = $-$1.100 $\times$ water% + 78.753, $r^2 = 0.95$, $P \leq$ 0.001) for all deer. Water, protein, and ash accounted for 71.8 $\pm$ 0.5%, 23.9 $\pm$ 0.3%, and 4.1 $\pm$ 0.2% ($\pm$SE) of the fat-free, ingest-free body mass and these relationships were used to predict body protein (Appendix).

Correlation Analysis

All indices tested, except scapula muscle thickness, were significantly related to body fat ($P \leq 0.05$). For live animals, rLIVINDEX best predicted IFBF ($r^2 = 0.89$) and GE ($r^2 =$ 0.87; Fig. 1; Tables 1, 2). Both rumpBCS and MAXFAT alone also were highly related to IFBF and GE (Tables 1, 2), although MAXFAT displayed a slightly curvilinear relation at high levels of condition and was truncated at low levels of condition (below about 6% body fat, MAXFAT was constant at 0.2 cm). Live body mass alone was only moderately related to condition and failed to increase the correlation of the rumpBCS when they were combined into a body reserve index (Fig. 1; Tables 1, 2). Of the muscle measurements, only longissimus dorsi thickness was significant, but moderately related to both IFBF and GE ($r^2 =$ 0.32; Fig. 1; Tables 1, 2).

For dead animals, the modified Kistner Score and the CONINDEX were most related to condition (Fig. 1; Tables 1, 2) but the Kistner Score was slightly curvilinear particularly at high levels of condition. The subset Kistner Score (heart, pericardium, and kidneys) was less correlated ($r^2 = 0.79$) than the entire score. Removing the heart score and using only the pericardium and kidneys together resulted in a subset index comparable to using the entire score (r^2 = 0.89). The Wyoming Index was moderately related to condition, but only when subcutaneous fat was

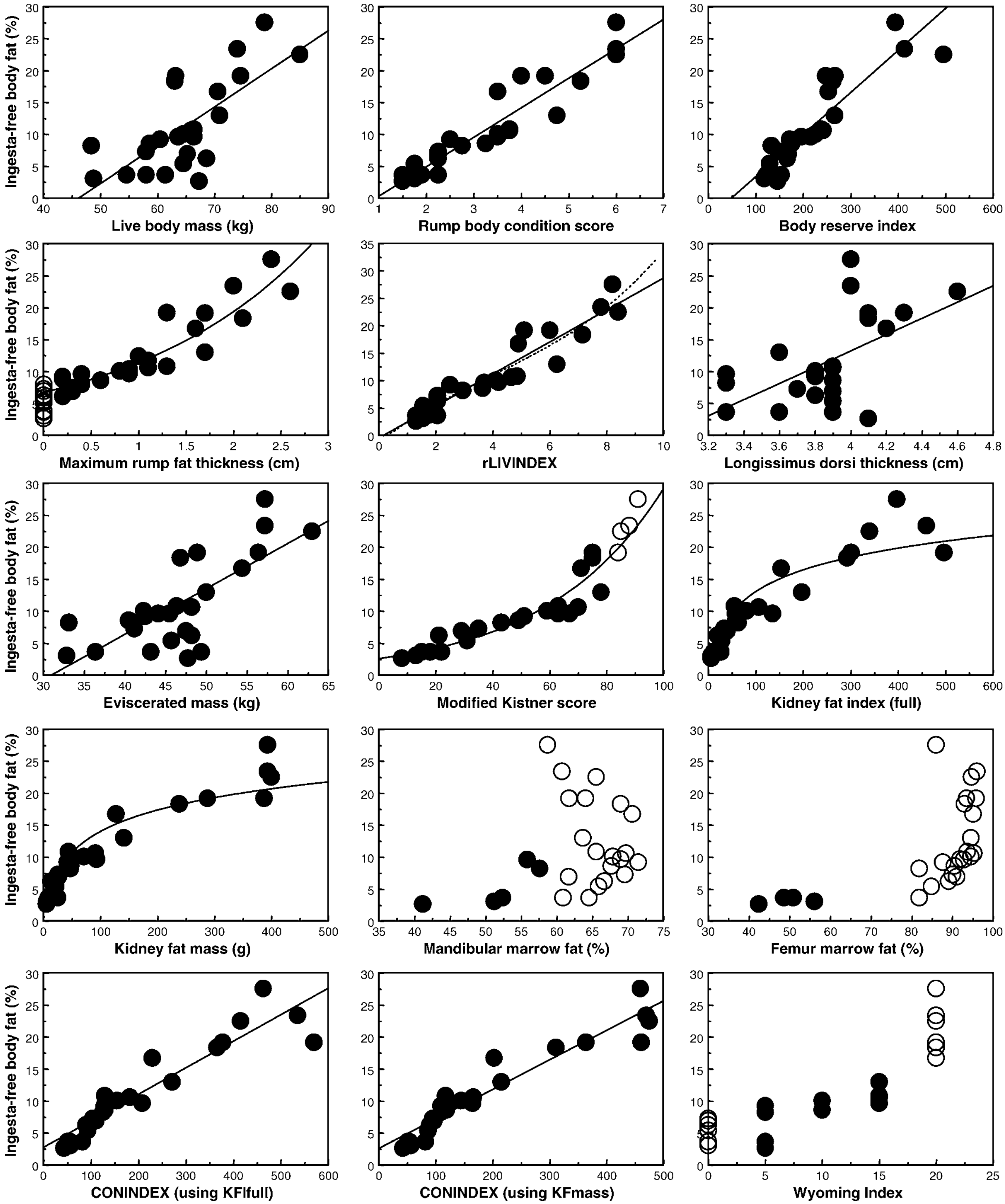

Figure 1. Relations of 15 nutritional condition indices with ingesta-free body fat (IFBF) percent for 25 mule deer collected during 2002–2004 in Oregon, Washington, and California, USA. Open circles represent the range where an index loses predictive ability (e.g., max. rump fat thickness, marrow fat indices, and Wyoming index). We present both a linear relation to IFBF for maximum rump fat thickness and a polynomial relation (IFBF [%] $= 0.03318x^3 - 0.39389x^2 + 4.12406x - 1.3719$; IFBF [kg] $= 0.047863x^3 - 0.478769x^2 + 3.14240x - 1.79641$).

Table 1. Regression equations for predicting ingesta-free body fat (% and kg) to estimate nutritional condition of mule deer. Equations were developed using 25 mule deer collected during 2002–2004 in Oregon, Washington, and California, USA. All regression equations are significant ($P \leq 0.001$). Standard error of the estimate ($S_{y \cdot x}$) is presented for each predictive equation.

Condition index[a]	Ingesta-free body fat (%)				Ingesta-free body fat (kg)				Eq form
	b	*a*	r^2	$S_{y \cdot x}$	*b*	*a*	r^2	$S_{y \cdot x}$	
rLIVINDEX	2.920	−0.496	0.89	2.34	2.231	−1.979	0.85	2.21	$y = bx + a$
MAXFAT (cm)[b,c]	0.530	6.706	0.87	2.24	0.751	2.990	0.84	2.07	$y = ae^{bx}$
Rump condition score	4.622	−4.328	0.88	2.50	3.519	−4.868	0.83	2.34	$y = bx + a$
Body reserve index	0.066	−3.260	0.82	3.06	0.054	−4.760	0.87	2.02	$y = bx + a$
Body mass (kg)	0.599	−27.650	0.51	5.03	0.514	−26.388	0.61	3.52	$y = bx + a$
Loin muscle depth (cm)	12.734	−37.712	0.32	5.88	11.050	−35.546	0.38	4.41	$y = bx + a$
Modified kistner score	0.027	2.213	0.92	2.06	0.037	0.665	0.87	1.90	$y = ae^{bx}$
$\text{Kistner}_{(\text{heart, pericardium, kidneys})}$	0.060	1.430	0.79	3.29	0.080	0.419	0.72	2.97	$y = ae^{bx}$
$\text{Kistner}_{(\text{pericardium, kidneys})}$	0.079	1.937	0.85	2.80	0.112	0.518	0.83	2.34	$y = ae^{bx}$
$\ln(\text{KF}_{\text{mass}})$	4.803	−8.094	0.87	2.57	3.581	−7.430	0.79	2.60	$y = bx + a$
$\ln(\text{KFI}_{\text{full}})$	4.907	−9.554	0.84	2.85	3.614	−8.332	0.74	2.86	$y = bx + a$
$\ln(\text{KFI}_{\text{trim}})$	5.844	−11.873	0.81	3.11	4.305	−10.040	0.73	3.01	$y = bx + a$
$\text{CONINDEX}_{\text{KFIfull}}$	0.042	2.723	0.87	2.54	0.032	0.508	0.82	2.38	$y = bx + a$
$\text{CONINDEX}_{\text{KFmass}}$	0.046	2.780	0.92	2.10	0.036	0.228	0.91	1.74	$y = bx + a$
Wyoming index	0.740	3.640	0.75	3.60	0.552	1.311	0.68	3.20	$y = bx + a$
Mandibular marrow (%)	0.008	−0.668	0.40	0.08	0.017	−1.323	0.34	0.17	$-1/y = bx + a$
Femur marrow (%)	0.005	−0.578	0.79	0.04	0.011	−1.149	0.68	0.12	$-1/y = bx + a$
Eviscerated mass (kg)	0.709	−21.951	0.54	4.85	0.609	−21.497	0.65	3.34	$y = bx + a$

[a] When subcutaneous rump fat thickness (MAXFAT) $\geq$ 0.2 cm, rLIVINDEX = (MAXFAT − 0.2) + rump body condition score (rumpBCS), and when MAXFAT < 0.2 cm, rLIVINDEX = rumpBCS. KF_{mass}, kidney fat mass. KFI, kidney fat index.
[b] Only measurements $\geq$0.2 cm were used to determine parameter estimates; values <0.2 cm should not be used in this eq.
[c] Includes 9 ad F mule deer data points from Stephenson et al. (2002).

present. With logarithmic transformations, kidney fat mass (KF_{mass}) alone was superior to full KFI (KFI_{full}), and KFI_{full} was superior to the traditional method of trimming (KFI_{trim}; Fig. 1; Tables 1, 2). Using KF_{mass} ($r^2 = 0.92$) to develop the CONINDEX produced a better relation than using KFI_{full} ($r^2 = 0.87$).

Coefficients of determination for femur, mandibular, and metatarsal marrow fat were 0.79, 0.40, and 0.41, respectively, with IFBF using transformations of the dependent variable, and all were highly curvilinear (Fig. 1, Table 1).

Range of Usefulness

We observed 5 types of depletion patterns (Fig. 2), each of which correspond to different ranges of usefulness. Type I

Table 2. Regression equations for predicting gross energy (Mcal/kg and Mcal) to estimate nutritional condition of mule deer. Equations were developed using 25 mule deer collected during 2002–2004 in Oregon, Washington, and California, USA. All regression equations are significant ($P \leq 0.001$). Standard error of the estimate ($S_{y \cdot x}$) is presented for each predictive equation.

Condition index[a]	Gross energy (Mcal/kg)				Gross energy (Mcal)				Eq form
	b	*a*	r^2	$S_{y \cdot x}$	*B*	*a*	r^2	$S_{y \cdot x}$	
rLIVINDEX	0.247	1.227	0.87	0.22	22.979	39.562	0.80	26.92	$y = bx + a$
MAXFAT (cm)[b,c]	0.253	1.771	0.82	0.22	0.462	79.421	0.82	23.74	$y = ae^{bx}$
Rump condition score	0.390	0.905	0.85	0.24	36.099	10.328	0.77	28.53	$y = bx + a$
Body reserve index	0.006	0.995	0.79	0.28	0.563	8.326	0.86	22.64	$y = bx + a$
Body mass (kg)	0.050	−1.033	0.48	0.44	5.746	−240.896	0.68	34.04	$y = bx + a$
Loin muscle depth (cm)	1.105	−2.030	0.32	0.51	125.942	−352.621	0.45	43.97	$y = bx + a$
Modified kistner score	0.010	1.264	0.85	0.24	0.013	60.882	0.76	29.72	$y = ae^{bx}$
$\text{Kistner}_{(\text{heart, pericardium, kidneys})}$	0.021	1.120	0.72	0.32	0.035	41.113	0.60	37.80	$y = ae^{bx}$
$\text{Kistner}_{(\text{pericardium, kidneys})}$	0.029	1.223	0.79	0.29	0.050	45.742	0.70	32.55	$y = ae^{bx}$
$\ln(\text{KF}_{\text{mass}})$	0.409	0.573	0.86	0.23	37.128	−17.544	0.75	29.86	$y = bx + a$
$\ln(\text{KFI}_{\text{full}})$	0.416	0.457	0.82	0.26	27.304	−26.190	0.70	32.66	$y = bx + a$
$\ln(\text{KFI}_{\text{trim}})$	0.496	0.259	0.80	0.28	44.434	−43.819	0.68	34.01	$y = bx + a$
$\text{CONINDEX}_{\text{full}}$	0.004	4.496	0.86	0.23	0.325	65.341	0.77	28.68	$y = bx + a$
$\text{CONINDEX}_{\text{KFmass}}$	0.004	1.483	0.90	0.20	0.373	61.890	0.86	22.14	$y = bx + a$
Wyoming index	0.063	1.568	0.75	0.31	5.757	72.752	0.65	35.18	$y = bx + a$
Mandibular marrow (%)	0.007	−0.889	0.15	0.11	0.0002	−0.018	0.11	0.00	$-1/y = bx + a$
Femur marrow (%)	0.005	−0.912	0.50	0.08	0.0001	−0.019	0.37	0.00	$-1/y = bx + a$
Eviscerated mass (kg)	0.060	−0.587	0.53	0.42	6.898	−190.863	0.74	30.42	$y = bx + a$

[a] When subcutaneous rump fat thickness (MAXFAT) $\geq$ 0.2 cm, rLIVINDEX = (MAXFAT − 0.2) + rump body condition score (rumpBCS), and when MAXFAT < 0.2 cm, rLIVINDEX = rumpBCS. KF_{mass}, kidney fat mass. KFI, kidney fat index.
[b] Only measurements $\geq$0.2 cm were used to determine parameter estimates; values <0.2 cm should not be used in this eq.
[c] Includes 9 ad F mule deer data points from Stephenson et al. (2002).

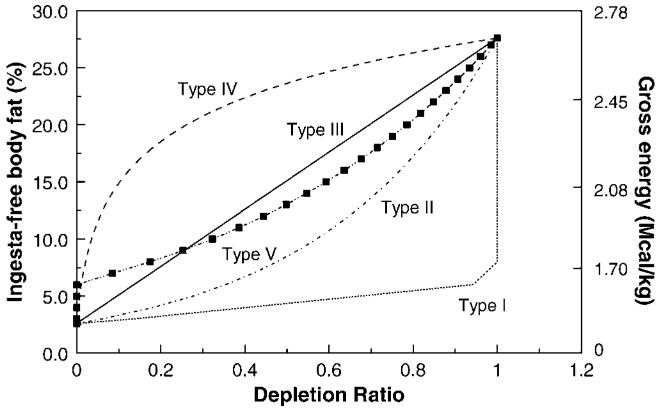

Figure 2. Potential depletion patterns of nutritional condition indices of large ungulates (adapted from Cook et al. 2001*b*). Each curve represents a different type of relation to body fat: Type I, almost asymptotic (marrow indices); Type II, exponential (Kistner and subset scores); Type III, linear (rump body condition score, rLIVINDEX, CONINDEX, body mass); Type IV, logarithmic (kidney fat indices); and Type V, linear or exponential but truncated (max. subcutaneous rump fat thickness, Wyoming index). Depletion ratios were standardized across indices (with 1 being the highest value attained for that particular index for the range of condition in this study [no depletion], and 0 being the lowest value attained for that particular index for the range of condition in this study [complete depletion]). Although we presented the curves with actual fat values, these should be used as relative values only. Within a type, individual curves vary due to different equation coefficients.

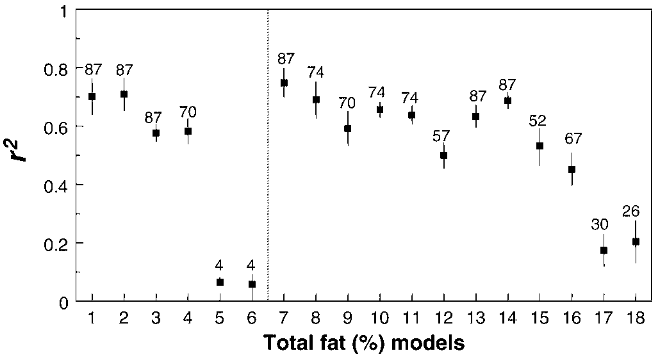

Figure 3. Sensitivity of 18 nutritional condition models evaluated in this mule deer nutritional condition study, 2002–2004. We evaluated sensitivity by subjecting each model to 26 regressions within a restricted range of condition (7 percentage points of body fat representing within-season variation of condition of wild mule deer herds in WA; W. L. Myers, Washington Department of Fish and Wildlife, unpublished data). The average coefficient of determination (±SE) and the percentage of time the model was statistically significant over the 7-point ranges are presented. Models used were 1) rump body condition score; 2) rLIVINDEX; 3) maximum subcutaneous rump fat thickness; 4) body reserve index; 5) body mass; 6) longissimus dorsi thickness; 7) modified Kistner score; 8) heart, pericardium, kidneys subset score; 9) pericardium and kidneys subset score; 10) kidney fat mass (KF_{mass}); 11) kidney fat index (full), (KFI_{full}); 12) kidney fat index (trim); 13) CONINDEX using KFI_{full}; 14) CONINDEX using KF_{mass}; 15) Wyoming Index; 16) femur marrow fat; 17) mandibular marrow fat; 18) eviscerated body mass.

approaches an asymptotic relationship to IFBF and included all the marrow fat indices. Indices within this category were strongly limited in their predictive capability. They displayed no predictive ability (slope approaches vertical) at moderate to high levels of condition and were related to condition only at low levels of condition. Type II is an exponential relationship and included the Kistner score and its subset scores. Despite a slightly curvilinear relation with total body fat, indices in this category showed predictive capability across the whole spectrum of body condition, although sensitivity of the index to condition changed at different levels of condition. Type III is a linear relation to IFBF and included the rumpBCS, rLIVINDEX, body reserve index, body mass, and CONINDEX. Indices within this category showed consistent predictive capability across the entire spectrum of body condition. Type IV is a logarithmic relation and included all the kidney fat indices. Indices within this category changed rapidly with changing condition at low levels of animal condition (slope approaching zero), but changed relatively little with changing condition at high levels of condition (slope approaching vertical). Type V is either a linear or an exponential relation, but has an abruptly truncated range of usefulness and included MAXFAT and Wyoming index. Indices within this category showed predictive capability at moderate to high levels of condition but lost predictive ability at low levels of condition.

Model Sensitivity

When restricted to ranges of condition that would typically be found within a season (e.g., 7 percentage points of fat in native mule deer populations of central WA), coefficients of determination generally were lower than found for the larger, among-season ranges on which the equations were developed (Fig. 3). Rump body condition score (Model 1), rLIVINDEX (Model 2), MAXFAT (Model 3), Kistner score (Model 7), kidney fat mass (Model 10), KFI_{full} (Model 11), CONINDEX using KFI_{full} (Model 13), and CONINDEX using kidney fat mass (Model 14) were significantly related to body fat ($P \leq 0.05$) for >80% of the 26 data subsets. Body reserve index (Model 4), both Kistner subset scores (Models 8 and 9), and femur marrow fat (Model 16) were significantly related to body fat ($P \leq 0.05$) for >60% of the 26 data subsets. However, body mass (Model 5), thickness of longissimus dorsi muscle (Model 6), KFI_{trim} (Model 12), Wyoming index (Model 15), mandibular marrow fat (Model 17), and eviscerated body mass (Model 18) were significantly related to body fat ($P \leq 0.05$) for ≤60% of the 26 data subsets. Body mass (Model 4), thickness of longissimus dorsi muscle (Model 6), mandibular marrow fat (Model 17), and eviscerated body mass were markedly insensitive; they were significantly related to body fat for <50% of the 26 data subsets.

DISCUSSION

Correlation Analysis

For data collected on live mule deer, maximum subcutaneous fat thickness, a rump body condition score, and an arithmetic combination of both (rLIVINDEX) provided the highest correlation with IFBF and GE. However, the rump fat layer in mule deer is depleted at IFBF <6%, thus restricting its usefulness in thin animals (see also Cook et al. 2001*a*, *b*; Stephenson et al. 2002). The thickness of the longissimus dorsi muscle shared a logarithmic relation to

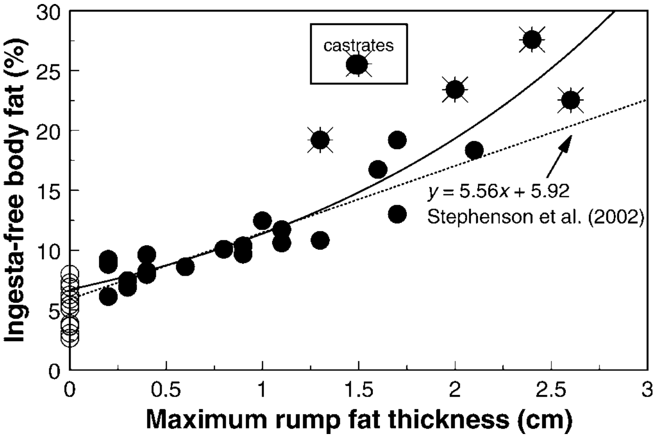

Figure 4. Relations of maximum rump fat thickness to total body fat (%). Closed circles represent mule deer with rump fat present, open circles represent deer without rump fat present. We only used the former to calculate equations. The solid line represents combined data from Stephenson et al. (2002) and this study ($n = 25$ mule deer collected during 2002 to 2004 in OR, WA, and CA, USA) showing a slightly exponential relationship to ingesta-free body fat (%). The dotted line represents Stephenson et al.'s (2002) original data showing a linear relation to ingesta-free body fat (%). Note that the equation presented here differs slightly from that presented in Stephenson et al. (2002); we only used animals with measurable rump fat to develop the equation.

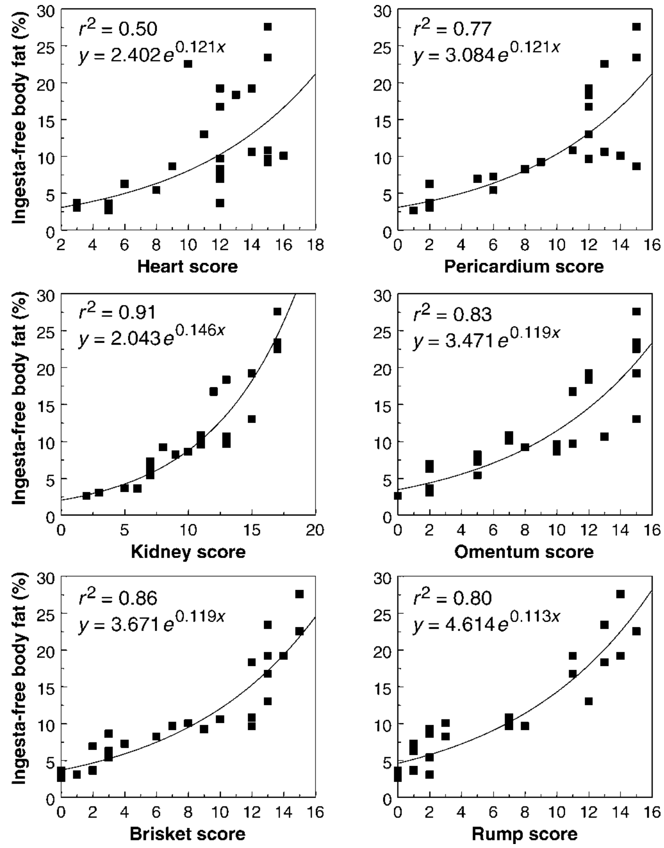

Figure 5. Relations of individual components of the modified Kistner score to total body fat (%) for 25 mule deer collected during 2002–2004 in Oregon, Washington, and California, USA. Each are scored from 1 to 15 or 20 in 1 point increments.

IFBF with moderate correlations. However, in elk, this relation varies with animal size, subspecies, and possibly other variables (R. Cook, National Council for Air and Stream Improvement, unpublished data), and may only provide a threshold indication of elevated protein catabolism in very thin animals (Cook et al. 2004).

For dead mule deer, the full, or some subset of the Kistner score and the CONINDEX provided the highest correlation. Kidney and marrow fat indices showed moderate correlation with IFBF and GE but were highly curvilinear, restricting their use (Cook et al. 2001*b*). The Wyoming Index was strongly curvilinear and imprecise at high levels of condition; thus, its use should probably be limited to coarse, herd-level evaluations of condition.

Indices developed for mule deer in our study were similarly predictive for moose (Stephenson et al. 1998) and elk (Cook et al. 2001*a*). Our findings also were similar to those of previous studies of mule deer (Watkins et al. 1991, Stephenson et al. 2002) but with several differences. Although linear relationships between both MAXFAT and the Kistner score with IFBF were reported for moose (Stephenson et al. 1998), elk (Cook et al. 2001*a*), and mule deer (Stephenson et al. 2002) a slightly curvilinear fit best represented the range of condition of mule deer used in this study. Our study included animals with up to 28% IFBF, well above the highest condition levels used in other studies (approx. 19% IFBF for moose and elk and approx. 12% for deer). The curvilinear relation between MAXFAT and IFBF when animals had less than approximately 15% IFBF (Fig. 4) may be caused by: 1) a surface area effect where at some given area of subcutaneous fat covering, an increase in rump fat thickness results in a larger contribution to IFBF, thus producing a nonlinear relation; 2) possible differences in fat deposition and depletion patterns of castrated males (however, out of 7 data points causing the curvilinear relation, 3 of these were F [Fig. 4]); or 3) fat deposition and depletion patterns of obese mammals may not follow patterns of thinner animals. Whatever the reason, for mule deer that are not overly obese (i.e., $<$20% fat), our nonlinear and Stephenson's et al. (2002) linear equation (constructed with deer $\leq$12% IFBF) provides virtually identical estimates of body fat (Fig. 4).

For an index using categories to score, such as the Kistner score (Fig. 1), a nonlinear relationship that curves up at high levels of condition indicates that small errors in estimating the index will result in relatively large errors in estimates of body fat, at high levels of condition. To make the Kistner score more linear, the upper level of scoring could be substantially increased to account for these fatter animals. Although we did increase the upper level of scoring for several of the organ evaluations, we did not attempt to formalize a substantially different scoring system to account for condition levels rarely seen in free-ranging animals (C. Bishop, Colorado Division of Wildlife, and L. Bender, United States Geological Survey, personal communication; T. R. Stephenson, California Department of Fish and Wildlife, and W. L. Myers, unpublished data). Instead, we caution researchers to consider the limitation of this index if they encounter very obese animals.

Finally, in contrast to findings for elk by Cook et al. (2001*a*), we found a poor correlation for the subset Kistner score (i.e., the heart, pericardium, and kidney scores). This difference was due to a weak relation between the heart score and body fat (Fig. 5; $r^2 = 0.50$ vs. $r^2 = 0.77 - 0.91$ for the other individual components of the Kistner score). By removing the heart score and using only the kidney and pericardium scores, we obtained a new subset score for mule deer that was similar in accuracy to the whole Kistner Score (Tables 1, 2) but more practical to collect in many field situations.

Range of Usefulness Analysis

Range of usefulness varies as a function of the specific form of the relation between each index and animal condition, which, in turn, largely results from sequential patterns of fat mobilization across the body (Harder and Kirkpatrick 1994). As condition declines, fat mobilization is believed to occur in subcutaneous depots first, viscera including the kidneys next, and finally in the marrow (Cederlund et al. 1989).

The different curve types of the indices we evaluated (Fig. 2) illustrate this general pattern of fat mobilization. Transforming these data to make relations between indices and condition more linear usually produce high correlation coefficients, but biological implications of such nonlinear relationships are masked (Robbins 1983). The curve types also identify levels of condition across which specific indices are most accurate in predicting body fat. In general, indices exhibiting Type I curves (marrow indices) have little sensitivity at moderate and high levels of condition and probably are of value only in winter and spring. Indices with Type V curves (MAXFAT and Wyoming Index) are marginally useful at low levels of condition and probably are of value only in summer and autumn. Indices with Type IV curves (kidney fat indices) are most valuable at moderate levels of condition and optimum season of use will depend on fat characteristics of the herd. Indices that are linear across the entire range of condition (Type III) or slightly curvilinear (Type II) greatly facilitate comparisons among herds, among seasons, and across time (e.g., body condition scores, Kistner scores, rLIVINDEX, CONINDEX).

In general, this analysis indicated that range of usefulness of indices based on only one fat depot (subcutaneous fat thickness, kidney fat indices, marrow fat indices) will be limited to some extent, and that range of usefulness will be greatest for indices that include measurements of >1 fat depot or muscle (Kistner scores, body condition scores, rLIVINDEX, CONINDEX).

Sensitivity Analysis

Our sensitivity analysis revealed similar patterns as reported for elk (Cook et al. 2001*b*). In general, our sensitivity analysis showed that models with even small differences in coefficients of determination differed in their ability to predict within-season ranges of percent fat (Fig. 2). Indices with moderate correlations to body fat (e.g., body mass), curvilinear relations (kidney and marrow fat indices), or indices based on a relatively small number of categories (e.g., Wyoming Index) provided poor predictive capability within seasons.

Additional Considerations

Experience we have gained over the past decade in developing, using, and training others demonstrates that observer bias and errors and, thus, adequacy of training, must be carefully considered for reliable application of many of the techniques described herein. Conventional wisdom suggests that indices based on visual evaluation or palpation (e.g., Kistner score, body condition score) are subjective and prone to bias, whereas indices based on actual measurements (e.g., kidney fat indices and those using ultrasonography) are objective and, thus, unbiased. However, we caution against these generalizations—our experiences indicate that objective indices do not necessarily produce better data and may be more prone to large errors. Below, we provide an initial categorization for each index.

1. Highly prone to error or bias: ultrasonography-based techniques (subcutaneous rump fat, muscle thickness) and body condition scores. Inexperienced personnel routinely make a number of serious mistakes with ultrasonography, such as measuring in the wrong location, incorrectly angling the probe, or measuring the wrong tissue layer (R. Cook, unpublished data). Mistaking muscle layers for fat layers may result in estimates of >15% IFBF for animals actually having <5% IFBF. Failing to distinguish between fascia and fat layers, a problem that becomes more important once rump fat has been depleted, can produce estimates of body fat of 6–7% when body fat may be <1% (thus, we strongly recommend utilizing the MAXFAT equation only when rump fat thickness is >0.2 cm; when animals have measurements falling below that point, other indices should be used). Lastly, our body condition score simply cannot be used reliably without extensive, repetitive training using animals with a broad range of nutritional condition.
2. Moderately prone to error or bias: kidney fat indices. In addition to problems noted for kidney fat indices by others (Finger et al. 1981; Robbins 1983; Depperschmidt et al. 1987; Cook et al. 2001*a*, *b*), we have found that determining which fat is associated with the kidneys rather than other internal organs can be subjective and may introduce error. The amount of error or bias due to collecting fat by untrained personnel evidently is assumed negligible, but has never been evaluated, to our knowledge. For trained personnel, this probably is a minor problem, but untrained hunters often are used to collect kidney fat samples (e.g., see Kohlmann 1999).
3. Little prone to error or bias: Kistner score, Wyoming index, marrow fat indices (if collected when fresh before water loss from marrow tissue occurs). The Kistner score and its subsets are a visual-based, subjective index, yet have consistently proven to be an accurate and sensitive measure of body condition in ungulates (Watkins et al.

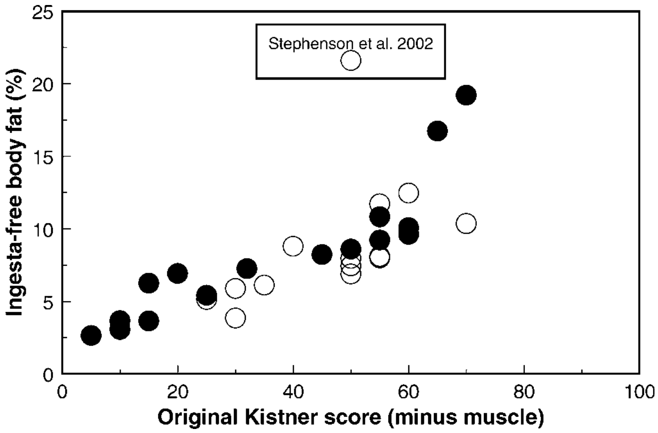

Figure 6. Relations between the original Kistner score and ingesta-free body fat from 2 independent scorers (both working separately, with different deer carcasses, and neither with prior training). Open circles represent the scores generated independently by Stephenson et al. (2002; *n* = 14 mule deer); closed circles represent the scores generated by the current study for deer falling within the same range of condition (*n* = 16 mule deer collected during 2002–2004 in OR, WA, and CA, USA). The relations generated from the 2 studies were basically identical, suggesting a level of robustness across users.

1991; Cook et al. 2001*a*, *b*; Stephenson et al. 2002). Moreover, based on data from 2 independent scorers (both working separately, with different deer carcasses, and neither with prior training), relations between the Kistner score and body fat were virtually identical (Fig. 6), suggesting a good level of robustness. The simple presence–absence fat measurement approach of the Wyoming index, and the clearly demarcated marrow tissue in bones, should make both reasonably immune to observer biases.

MANAGEMENT IMPLICATIONS

Condition indices provide tools for a variety of research and monitoring designs useful for evaluating nutrition's effect on populations. Goals might include simple monitoring to determine the need for more detailed and expensive nutritional evaluations or more complex studies of habitat's bottom-up influences on population dynamics. Our data identify several new techniques and infrequently used older techniques that have good predictive capability across wide ranges of nutritional condition and are reasonably practical. In particular, rLIVINDEX is a robust tool for live animals and, thus, is useful for evaluations of unhunted herds, during times of the year in which hunting or significant mortalities do not occur, for unhunted segments (e.g., F) of populations, or when repeated samples of individuals are essential. Similarly, the Kistner score is superior for dead animals; it could be implemented in a monitoring program at hunter check stations, for example, for evaluating spatial or temporal trends in condition (Austin et al. 1989). Whatever the objective, the nature and extent of data required to address key issues must be carefully considered in the context of costs and interpretive value, reliability of each condition index, and various research designs.

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Appendix. Calculation of ingesta-free body mass, body water, body protein, and ash for mule deer. Equations were developed using 25 mule deer collected during 2002–2004 in Oregon, Washington, and California, USA.

Dependent variable	Predictive eq_1	Predictive eq_2
IFBM[a]	1.113 (BM[b]) − 14.832; $r^2 = 0.86$	
Water%	−0.869 × Fat% + 71.03; $r^2 = 0.95$	
Water (kg)	0.35 × BM + 12.19; $r^2 = 0.53$	0.45 × EVWT[c] + 13.94; $r^2 = 0.66$
LBM[d] (kg)	Water(kg)/0.720	
LBM%	Water%/0.720	100 − Fat%
Protein (kg)	0.347 × Water(kg)	LBM × 0.239
Protein%	LBM% × 0.239	
Ash%	LBM% × 0.041	
Ash (kg)	LBM% × 0.041	

[a] Ingesta-free body mass. Only wild F deer were used to develop this relation.
[b] Live animal body mass.
[c] Eviscerated body mass.
[d] Fat-free, ingesta-free lean body mass.

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