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PREDICTION OF BODY COMPOSITION OF LIVE AND POST-MORTEM RED FOXES

Christine Lefebvre,[1,2] Michel Crête,[2,3,5] Jean Huot,[1,2] and Robert Patenaude[4]

[1] Département de biologie, Pavillon Vachon, Université Laval, Sainte-Foy, Québec, Canada, G1K 7P4
[2] Centre d'études nordiques, Université Laval, Sainte-Foy, Québec, Canada, G1K 7P4.
[3] Service de la faune terrestre, Ministère de l'Environnement et de la Faune, 675 boul. René-Lévesque Est (BP92), Québec, Québec, Canada, G1R 5V7
[4] Jardin zoologique du Québec, 9141 avenue du Zoo, Charlesbourg, Québec, Canada, G1G 4G4
[5] Corresponding author (e-mail: michel.crete@mef.gouv.qc.ca)

ABSTRACT: A series of measurements (lengths, circumferences, skinfolds, masses and resistance) was taken on 29 red foxes (*Vulpes vulpes*) of both sexes before and after their death during the autumns of 1994 and 1995. Body composition of each carcass was determined by chemical analysis of homogenized samples of viscera, carcass and skin. Eight multiple regression models were then developed to predict body water, fat, protein, and mineral mass using body measurements as independent variables taken on live or dead animals. All final models were highly significant ($P < 0.0001$) and included three or four explanatory variables. Adjusted coefficients of determination varied between 0.95 for water mass and 0.81 for mineral mass. The models cover a wide range of conditions as percent body fat in the 29 samples varied between 1.1 and 28.4%. Our models can serve for management or research purposes with live or dead red foxes as they are quick, inexpensive and nondestructive.

Key words: Composition, fat, fox, minerals, prediction, protein, regression, *Vulpes vulpes*, water.

INTRODUCTION

Understanding the dynamics of animal body composition is of great importance for ecological studies, because it can be related to survival (Peterson, 1977) and reproductive success (Poulle et al., 1995). The body composition of an animal also reveals its physical condition and can provide cues on habitat quality, in addition to identifying critical times or events in its life cycle (Farley and Robbins, 1994). Many studies (Huot and Picard, 1988; Buskirk and Harlow, 1989; Prestrud and Nilssen, 1992; Poulle et al., 1995) have related indices of body composition with values obtained by chemical extraction, but only a few models have been developed for live animals (Roby, 1991; Farley and Robbins, 1994). Obtaining sample sizes adequate for management and research purposes necessitates fast and accurate methods of determining body composition of live and dead animals.

Body composition is usually obtained by grinding an animal to provide an homogenate for sampling and analysis (Huot et al., 1995), or by dissection and weighing (Adamczewski et al., 1987; Ouellet, 1992). However, because these methods are time-consuming, expensive and difficult to use in the field, researchers have relied on indices to estimate body composition. As fat reserves are the primary source of energy in case of nutritional deficiency, most of the indices are related to fat content (Poulle et al., 1995). Qualitative indices based on estimates of fat deposits in different parts of the body (Hammill, 1983) remain highly subjective and must be used cautiously by different observers (Prestrud and Nilssen, 1992). Body or carcass mass, kidney fat, femur marrow fat, and dorsal fat are the most commonly used indices (Huot, 1988). However, these measurements apply mainly to dead animals, which excludes the possibility to use these methods to monitor the condition of a given animal.

Several nondestructive methods also exist for assessing water and fat contents of mammals and birds: total body electrical conductivity (TOBEC; Pethig, 1979; Van Loan and Mayclin, 1987), near infrared interactance (IRI; Roby, 1991), isotopic wa-

ter dilution (IWD; Sheng and Huggins, 1979), and bioelectrical impedance analysis (BIA; Kushner, 1992) are the most commonly used. These methods depend on the close inverse relationship existing between body water and fat, and the presumed constancy of the protein and mineral contents of their dry, fat-free mass in mature animals (Robbins, 1989). TOBEC explained 99.1% of the variation in lean body mass of Northern Bobwhites (*Colinus virginianus*) when the birds were normally hydrated and properly restrained (Roby, 1991). However, this method applies only to small animals, available instruments being most accurate in the range of 50 to 250 g live mass (Castro et al., 1990). Larger apparatus designed for humans are very expensive and too large for use in the field (Roby, 1991). Although theoretically promising, IRI has proven to be disappointing in birds (Roby, 1991).

IWD and BIA are best adapted to mid-size animals. With IWD, body water is estimated by injecting a known dose of isotope, allowing it to equilibrate with the body water, and measuring its specific activity in a sample of body water (Pace et al., 1947; Lukaski, 1987; Gauthier and Thomas, 1990). BIA was originally developed for determining human body composition (Lukaski, 1987). BIA measures the resistance to conduction (in ohms) of a low-level alternating current in an organism. Because the conductivity of body lipids is only 4–5% that of lean tissues, body fluids, and bones (Pethig, 1979), the resistance measured by BIA gives an indicator of body water content (Fiorotto et al., 1987; Walsberg, 1988; Hall et al., 1989).

Body composition has been widely investigated in ungulates but to a lesser extent in mammalian carnivores (Kistner et al., 1980; Huot, 1988; Adamczewski et al., 1995). There is at present no satisfactory indirect method for estimating body components of live and dead red foxes (*Vulpes vulpes*). For carnivores, Buskirk and Harlow (1989) developed models to assess body composition of american marten (*Martes americana*), Prestrud and Nilssen (1992) for the arctic fox (*Alopex lagopus*), and Huot et al. (1995) for coyotes (*Canis latrans*). They tested the relationships between selected indices and ingesta-free body composition determined by chemical analysis. In the present study, we aimed at developing reliable models for predicting body composition of red foxes from indices readily available on live animals or on carcasses.

METHODS

Sampling

Red foxes (16 males and 13 females) were collected by trappers and government personnel within a 250 km radius of Québec City (Québec, Canada; 46°30′ to 47°15′N, 69°15′ to 71°30′W) during the autumns of 1994 and 1995. They were captured with padded foot traps (Victor Coil No. 3, Animal Trap Co., Lititz, Pennsylvania, USA) and snares equipped with a safety catch (Les entreprises Makwa Inc., Saint-Émile, Québec, Canada). After catching, foxes were immobilized with a catch pole, carried inside, and then anesthetized by intramuscular injection with a mixture of Rogarsetic® 26.7 $mg \cdot kg^{-1}$ (Rogar STB, London, Ontario, Canada) and Rompun® 8.9 $mg \cdot kg^{-1}$ (Bayer Inc., Etobicoke, Ontario, Canada) for a series of measurements. This study was approved by the Animal Protection Committee of Université Laval (No. 93-276; Sainte-Foy, Québec, Canada) and the work was conducted in conformity with the guidelines issued by the Canadian Council of Animal Protection (Ottawa, Ontario, Canada).

Measurements on live red foxes

Animals were weighed (total body mass, TBM; Sumbeam, Chubutu, Missouri, USA; graduation ± 100 g) and measured with a tape (graduation ± 5 mm; Fig. 1). Measurements included total length (TL) as the distance between the anterior edge of the muzzle to the tip of the last vertebra, body length (BL) as the distance between the anterior edge of the muzzle to the base of the tail as determined by placing it perpendicular to the back, front limb length (FLL) from the dorsal edge of the scapula to the longest claw of the extended limb, posterior limb length (PLL) from the iliac crest to the last claw of the extended limb, foot length (FL) from the last claw to the tuber calcis, head circumference (HC) just in front of the ears, neck circumference (NC) approxi-

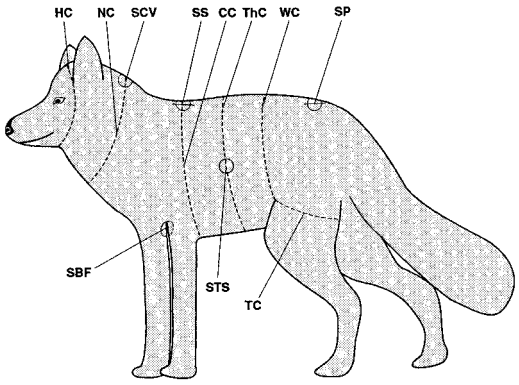

FIGURE 1. Morphometric measurements taken on live red foxes to predict body composition. Acronyms are defined in Table 1.

mately at the level of the third cervical vertebra, chest circumference (CC) right behind forepaws, thorax circumference (ThC) at the level of the distal part of the xiphoid cartilage of the sternum (Miller, 1962), waist circumference (WC) in front of hind paws, and thigh circumference (TC) at the proximal part of the thigh. When measuring circumferences, we exerted on the tape a tension equivalent to a mass of ≈500 g, measured with a spring scale (Pesola, Zug, Switzerland). We also measured skinfolds with a caliper (Slimguide®, Creative Health Products, Plymouth, Michigan, USA; graduation ±0.5 mm) at sites (Fig. 1) on the dorsal surface at approximately the third cervical vertebra (skinfold on cervical vertebrae, SCV), 1 cm behind scapulae (SS), between forepaws (SBF), on thorax side (STS) towards the distal part of the xiphoid cartilage, and on the back at the level of the pelvis (SP). For each of these sites, we took three measurements that were averaged for further analyses. Measurements taken when the animal was in a sternal position with legs in normal resting position were TL, BL, HC, NC, SCV, SS, and SP. Other measurements were taken when foxes were laid in a lateral position.

Bioelectrical impedance analyses

We measured BIA resistance and reactance in the scale 0-1000 and 0-500 ohms, respectively, with a Model 101A instrument (RJL Systems, Detroit, Michigan, USA). We used a consistent positioning of the fox (sternal with legs in normal resting position) and of the electrodes, because BIA readings are strongly affected by limb position and electrode distance (Kushner, 1992). We used snout to tail resistance. The anterior electrode pair was clamped to the upper lip, at the level of the canines, and the posterior electrodes were placed on either side of the anus, making sure that they were not in contact. Good electrical contact was ensured by wetting the electrodes and the lips and anus of the animal with water.

Isotopic water dilution

We could utilize IWD with only eight foxes (7 males and 1 female). We first took a blood sample of ≈3 ml from the jugular vein of each animal before injection as an individual control. We then injected 250 μl of tritiated water containing ≈0.88 MBq into the jugular vein. After 90 min, the estimated equilibration time, we collected ≈3 ml of blood from the same vein. We determined the equilibration time at the outset of the experiment with two foxes whose blood was sampled every 30 min for 3 hr. Blood samples were centrifuged (International Centrifuge, model CM, Boston, Massachusetts, USA) at 1,500 RPM for 10 min, and serum samples were collected and frozen for further analysis. From these samples, we pipetted 200 μl and added 10 ml of liquid scintillation cocktail (Ready Safe™, Beckman Instruments Canada, Inc., Mississauga, Ontario, Canada). The tritiated serum samples were counted with a liquid scintillation counter (LKB Wallac model: 1219 Rackbeta, Turku, Finland) and the tritium activity was expressed in desintegrations per min (DPM) per ml of water. We estimated total body water content from the quantity of tritium we injected to the fox and its concentration ($DPM \cdot ml^{-1}$) after 90 min.

Measurements on dead red foxes

Foxes were euthanized with 1.5 ml of T-61® (Hoechst Canada Inc., Regina, Saskatchewan, Canada), placed in plastic bags, frozen, and stored at −20 C until analysis. Frozen carcasses were thawed, weighed, skinned, leaving as much subcutaneous fat as possible on the carcass, and weighed again (skinned body mass, SBM). The digestive tract was then cleaned three times by making pressure on the tract from the esophagus to the rectum and weighed again (ingesta-free body mass, IFBM). Fat attached to each kidney (kidney fat mass, KFM) was removed and weighed (Sartorius 1364 MP, Göttingen, Germany; graduation ±0.01 g) separately as were the kidneys (kidney mass, KM). Fat attached on the pericardium (heart fat mass, HFM) and the heart (heart mass, HM) were similarly weighed. We calculated a kidney fat index (KFI = KFM × 100/KM, Riney, 1955) and a heart fat index (HFI = HFM × 100/HM, Huot et al., 1995). The viscera, which comprised all organs in the body cavity including the diaphragm, were removed. The evis-

cerated carcass was then weighed (ECM). The viscera mass (VM) was deducted by subtracting ECM from IFBM. Finally, one piece of femur marrow (femur marrow fat, FMF), approximately 5 cm long, was collected, weighed, and dehydrated.

Composition analyses

Before analysis, frozen carcasses were ground twice in a Hobart meat grinder (Model A-200, Hobart Co., Don Mills, Ontario); once through a 6 mm mesh size sieve and once through a 5 mm mesh size sieve. The homogenate was mixed mechanically between and after mincing. Three subsamples of about 100 g from each animal were collected and frozen again for chemical analyses. We followed the same procedure for viscera. Because of its resistance to grinding, hide was analysed separately. Samples of hide were haphazardly chosen, excluding paws and front of ears, then shaved, and chopped into small pieces. We attempted to obtain approximately 50 g of skin samples. Whole body composition was derived by summing carcass, viscera, and skin components in correcting for their different proportion of the whole body mass.

Water content was determined by freeze-drying the three subsamples of the homogenate for 72 hr (Labconco No. 5, Kansas City, Missouri, USA). The dried homogenates were ground with a blender and used for all subsequent chemical analyses. Fat was extracted from 1 g samples in a Soxhlet extractor (Soxtec System HT6, Tecator Inc., Herndon, Virginia, USA), using petroleum ether (Randall, 1974). Mineral content was estimated after overnight combustion of 4 to 5 g samples in a muffle furnace at 500 C. Protein content was calculated by subtracting water, fat, and mineral from total body mass; this procedure provides similar results as chemical determination of N content (Adamczewski et al., 1995). All analyses were duplicated and when differences between replicates exceeded 15% of the mean, a third analysis was performed. In all calculations, means were used.

Statistical analyses

We developed models to predict the four major body components of live and dead red foxes (water, fat, protein, and mineral) using multiple linear regression analyses (SAS, 1987). In a preliminary step, all dependent variables were plotted separately against independent ones to ensure linear relationships. Potential independent variables used were all morphometric and electric measurements and masses taken on live and dead foxes, which yielded eight multiple regression models. As measurements of BIA might not be widely available, models were also computed without considering it among the independent variables. A stepwise procedure served to select the best models, given the large number of possible independent variables. Final models included the multiple regressions with highest adjusted r^2, provided that residuals were homogenous (visual examination of the plot) and normally distributed (Shapiro-Wilk test). Examination of the variance inflation factor (VIF: Proc Reg; SAS, 1987) at each step ensured the absence of multicolineary. All final models included only those variables that contributed significantly ($P < 0.05$; in one case $P = 0.07$) to a r^2 increase of $\geq 1\%$. Complete information was not available for all specimens and consequently, sample sizes varied for different components. IWD was treated separately due to the small sample size, and we compared predicted and measured water body using a simple linear regression.

RESULTS

Total body mass of sampled red foxes averaged 3,676 ± 714 g ($\bar{x}$ ± SD; Table 1). Fat content varied from 36 to 1,362 g (253 ± 282); in percentage, body fat ranged from 1.1 to 28.4%. Water (2,336 ± 387), protein (884 ± 187) and mineral (179 ± 34) contents exhibited less variation among individuals.

All final models were highly significant ($P < 0.0001$) for live (Table 2) as well as for dead (Table 3) animals. For measurements taken on live foxes, the final model for water mass included TBM, BL, resistance, and WC ($r^2 = 0.96$). SS, WC, and BL served to predict absolute mass of fat ($r^2 = 0.90$). Protein mass was predicted with a three-variable regression model which included TBM, TC, and SS ($r^2 = 0.93$). PLL, STS, WC, and reactance were retained in the model predicting mineral mass ($r^2 = 0.84$). Without access to BIA measurements, r^2 of selected models dropped by ≈3%.

For dead foxes, the final model included TBM, KFI, and TC to predict water mass ($r^2 = 0.94$); KFI, ThC, SP, and SCV to estimate fat mass ($r^2 = 0.94$); TBM, HFM, TC, and FMF to predict protein mass ($r^2 = 0.95$) and SBM, KFM, and CC for min-

TABLE 1. Descriptive statistics of live and post-mortem measurements taken on red foxes collected in south-central Québec and used for regression models predicting ingesta-free body composition of red foxes.

Variable	Acronym	Mean	SD[a]	Range (min–max)	*n*
Water mass (g)		2,336	387.0	1,675–3,147	29
Fat mass (g)		252.6	281.5	36.1–1,362	29
Protein mass (g)		884.3	187.3	525.8–1,170	29
Ashable mineral mass (g)		179.2	33.6	120.9–261.9	29
Resistance (ohm)		466.0	31.6	407–529	26
Reactance (ohm)		60.6	8.3	43–77	26
Body length (cm)	BL	61.8	4.3	53.5–70.0	27
Chest circumference (cm)	CC	27.7	1.1	22.4–33.0	27
Femur marrow fat (%)	FMF	44.6	17.7	20.3–87.5	29
Heart fat mass (g)	HFM	1.84	2.01	0.0–9.1	29
Kidney fat index	KFI	22.6	20.7	3.8–95.6	29
Kidney fat mass (g)	KFM	5.71	5.86	0.9–26.1	29
Posterior limb length (cm)	PLL	44.2	3.5	37.4–50.5	27
Skinned body mass (g)	SBM	3,158	630.1	2,029–4,304	29
Skinfold on cervical vertebrae (mm)	SCV	3.5	0.9	2.2–6.0	27
Skinfold in the back at the level of pelvis (mm)	SP	4.5	1.5	3.0–9.3	27
Skinfold 1 cm behind scapulae (mm)	SS	3.7	1.1	2.7–7.7	27
Skinfold on thorax side (mm)	STS	3.3	0.9	2.0–6.0	27
Thigh circumference (cm)	TC	17.4	3.3	11.2–22.5	27
Thorax circumference (cm)	ThC	29.6	3.1	24.0–36.9	27
Total body mass (g)	TBM	3,676	714	2,400–4,800	29
Waist circumference (cm)	WC	21.2	3.4	15.7–31.1	27

[a] Standard deviation.

eral mass ($r^2 = 0.84$). As a supplementary independent variable in multiple regression, sex never significantly improved the fit for any model.

We found a close relationship between body water as determined by freeze-drying and IWD estimates ($r^2 = 0.92$; $n = 8$; Fig. 2); however all estimates were biased downward by ≈45%.

DISCUSSION

One might argue that non-linear regressions should better predict body components of red foxes, given that growth in mammals often follows a logistic pattern and that values reach an asymptote at both extremities of their range. In the present study, we intended to develop equations predicting the absolute mass of the four major body components of fully grown red foxes. Within the range of values available, there existed no evidence of curvature between the mass of each body components and the variables that served to estimate them. Curvature may appear though when expressing body components as percentage; with this respect, Bois et al. (1997) found, for white-tailed deer (*Odocoileus virginianus*), that estimates of percent body fat were more precise when derived from single prediction of each body component than from regressions relating directly percent fat with body measurements. All our linear regression models exhibited excellent fit, as revealed by their adjusted r^2, were exempt of biases within the range of data that served to compute them and covered a wide range of physical conditions (i.e., 1.1 to 28.4% of body fat). Extrapolation could be risky though and, for instance, negative fat masses may be predicted for very lean animals.

Even if regression models do not necessarily imply a cause-effect relationship between dependent and independent variables, the inclusion of most variables in

TABLE 2. Multiple regression models for predicting total ingesta-free body content (g) in water, fat, proteins and minerals of live red foxes.

Dependent variable[a]	Independent variable[b]	Partial r^2	r^2	Prob > F	Parameter estimate	SE[c]
Water	TBM	0.8154	0.8154	0.0001	0.41	0.07
n = 26	BL	0.0820	0.8974	0.0003	37.07	8.02
	resistance	0.0369	0.9343	0.0019	−2.43	0.66
	WC	0.0214	0.9557	0.0045	−33.03	10.38
	intercept				358.01	531.02
Water	TBM	0.8157	0.8157	0.0001	0.52	0.078
(without BIA readings)	WC	0.0653	0.881	0.0013	−43.67	12.62
n = 27	BL	0.0398	0.9208	0.0024	31.39	9.23
	intercept				−596.24	449.17
Fat	SS	0.8490	0.8490	0.0001	150.39	31.94
n = 27	WC	0.0205	0.8695	0.064	42.01	12.45
	BL	0.0311	0.9006	0.013	−15.88	5.92
	intercept				−212.85	281.05
Protein	TBM	0.8434	0.8434	0.0001	0.21	0.03
n = 27	TC	0.0516	0.8949	0.0022	22.96	5.75
	SS	0.0309	0.9258	0.0051	−41.37	13.36
	intercept				−128.59	61.85
Mineral	PLL	0.6674	0.6674	0.0001	7.98	1.01
n = 26	STS	0.0544	0.7218	0.045	−15.08	3.76
	WC	0.0862	0.808	0.0047	4.01	1.12
	reactance	0.0319	0.8399	0.054	−0.76	0.37
	intercept				−163.82	42.39
Mineral	PLL	0.6773	0.6773	0.0001	4.97	1.40
(without BIA readings)	TBM	0.0499	0.7273	0.047	0.02	0.007
n = 27	SCV	0.0856	0.8128	0.0036	−12.1	3.73
	intercept				−84.55	47.66

[a] n = number of animals used in the regression.
[b] See Table 1 for acronyms.
[c] Standard error of the estimate.

our models seems logical. For instance, there was at least one index of the animal's size in all equations, i.e., TBM, BL, PLL, SBM, WC, ThC, or CC. The model estimating water mass of live foxes included the resistance, a variable directly related to body water content. In the equation of body water for dead foxes, KFI replaced BIA measurements, which probably reflects the negative relationship between body fat and water in body composition (Farley and Robbins, 1994, Huot et al., 1995), including our samples (r^2 = 0.82; n = 29). Our estimates of body water with IWD were strongly biased for unexplained reasons. Other researchers also obtained unexplained biased estimates with IWD (Sheng and Huggins, 1971; Gauthier and Thomas, 1990). Given the cumbersome administrative and security constraints associated with the use of IWD and our disappointing results, we do not recommend this procedure for estimating body water.

The two regression models estimating body fat included either KFI and/or three skinfold sites on the back. Prestrud and Nilssen (1992) demonstrated that fat on the rump and back was the last subcutaneous fat to be depleted and the first to be deposited in the arctic fox, a pattern seemingly similar in the red fox. Alternatively, KFI was found to be related to total body fat in many mammal species (Finger et al., 1981; Torbit et al., 1988, Huot et al., 1995).

The two regressions predicting body

TABLE 3. Multiple regression models for predicting total ingesta-free body content (g) in water, fat, proteins and minerals of dead foxes.

Dependent variable[a]	Independent variable[b]	Partial r^2	r^2	Prob > F	Parameter estimate	SE[c]
Water	TBM	0.8157	0.8157	0.0001	0.74	0.05
n = 27	KFI	0.0819	0.8976	0.0002	−6.83	1.02
	TC	0.0451	0.9427	0.0003	−45.96	10.8
	intercept				595.84	111.46
Fat	KFI	0.7165	0.7165	0.0001	8.27	0.89
n = 27	ThC	0.1741	0.8906	0.0001	31.65	6.41
	SP	0.0308	0.9213	0.0064	58.7	14.87
	SCV	0.0232	0.9446	0.0061	−59.89	19.72
	intercept				−934.1	163.49
Protein	TBM	0.8434	0.8434	0.0001	0.21	0.03
n = 27	HFM	0.0596	0.903	0.0008	−37.53	8.71
	TC	0.0322	0.9353	0.0025	14.01	5.57
	FMF	0.0109	0.9462	0.046	2.42	1.15
	intercept				−187.4	58.6
Mineral	SBM	0.5959	0.5959	0.0001	0.09	0.01
n = 27	KFM	0.1806	0.7765	0.0002	−2.76	0.56
	CC	0.0656	0.8421	0.0051	−9.51	3.08
	intercept				159.39	47.38

[a] n = number of animals used in the regression.
[b] See Table 1 for acronyms.
[c] Standard error of the estimate.

protein included body mass as the major explanatory variable, similarly to models predicting body water. This is not surprising given that protein generally represents the second body component in mass. Both models also included a variable related to fatness (SS and FMF), likely reflecting the balance existing between protein, water, and fat in the body of mammals.

For live red foxes, the equation predicting mineral mass included PLL, an index of the skeleton size. This is plausible as the skeleton contains most of the body minerals (Adamczewski et al., 1995). The coefficients of determination for models predicting mineral masses were lower than the others. This may depend on an increased difficulty for predicting the mass of a small body component (≈5%; Zuercher et al., 1997; Voltura and Wunder, 1998). The lower precision of mineral predictions has limited consequences because this body component plays a minor role in the bioenergetics of mammals.

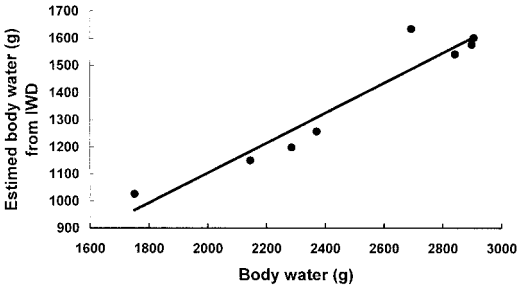

FIGURE 2. Linear relationship between body water of eight red foxes as determined by freeze-drying and estimated by isotopic (tritium) water dilution (IWD). The regression equation is: y = 8.598 + 0.548 × (r^2 = 0.92, n = 8).

Other studies on the estimation of body components of live mammals concerned mostly body water or fat and utilized TOBEC, BIA or IWD in addition to body mass to estimate water or fat mass (Farley and Robbins, 1994; Zuercher et al., 1997; Hilderbrand et al., 1998; Voltura and Wunder, 1998). Gerhart et al. (1996) used body score to estimate fat content of caribou whereas Jopson et al. (1997) utilized X-ray computed tomography to estimate

the mass of body fat, muscle and bone in fallow deer (*Dama dama*). For dead mammals, independent variables serving to estimate body components varied with the size of the species but generally included one variable related to body mass and/or one to body fat or water. In mesocarnivores, the total body mass often served in regression models (Huot et al., 1995; Y. Garant and M. Crête, unpubl. data) whereas a muscle or an organ mass commonly replaced body mass in large mammals due to the difficulty of weighing carcasses (Crête et al., 1993; Adamczewski et al. 1995; Bois et al., 1997).

Our models are versatile enough to correctly predict the body composition of both lean and fat red foxes of both sexes and can be used for comparing body composition on a yearly and regional basis. They are inexpensive, rapid to use, and nondestructive. However, some measurements, in particular circumferences, require careful readings. With canids, it may be particularly important to estimate all body components when interested in evaluating the physical condition of an animal or a population because fat, protein and water exhibit annual variations (Poulle et al., 1995; Lefebvre 1998). For instance, fat loss in summer could be normal in red fox or coyote but concurrent fat and protein loss likely indicates feeding deficiencies (Poulle et al., 1995; Lefebvre, 1998; Tremblay et al., 1998; M. Crête, unpubl. data).

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LITERATURE CITED

ADAMCZEWSKI, J. Z., P. F. FLOOD, AND A. GUNN. 1995. Body composition of muskoxen (*Ovibos moschatus*) and its estimation from condition index and mass measurements. Canadian Journal of Zoology 73: 2021–2034.

———, C. C. GATES, R. J. HUDSON, AND M. A. PRICE. 1987. Seasonal changes in body composition of mature female caribou and calves (*Rangifer tarandus groenlandicus*) on an arctic island with limited winter ressources. Canadian Journal of Zoology 65: 1149–1157.

BUSKIRK, S. W., AND H. J. HARLOW. 1989. Body-fat dynamics of the American marten (*Martes americanus*) in winter. Journal of Mammalogy 70: 191–193.

BOIS, C., M. CRÊTE, J. HUOT, AND J.-P. OUELLET. 1997. Prédiction de la composition corporelle post-mortem de cerfs de Virginie (*Odocoileus virginianus*) à partir de measures morphologiques et massiques. Canadian Journal of Zoology 75: 1790–1795.

CASTRO, G., J. P. WUNDER, AND F. L. KNOFF. 1990. Total body electrical conductivity (TOBEC) to estimate total body fat of free-living birds. Condor 92: 496–499.

CRÊTE, M., J. HUOT, R. NAULT, AND R. PATENAUDE. 1993. Reproduction, growth and body composition of Rivière George Caribou in captivity. Arctic 46: 189–196.

FARLEY, S. D., AND C. T. ROBBINS. 1994. Development of two methods to estimate body composition of bears. Canadian Journal of Zoology 72: 220–226.

FINGER, S. E., I. L. BRISBIN JR., M. H. SMITH, AND D. F. URBSTON. 1981. Kidney fat as a predictor of body condition in white-tailed deer. The Journal of Wildlife Management 45: 964–968.

FIORROTO, M. A., W. J. COCHRAN, R. C. FUNK, H. P. SHENG, AND W. J. KLISH. 1987. Total body electrical conductivity measurements: effects of body composition and geometry. American Journal of Physiology 252: R794–R800.

GAUTHIER, M., AND D. W. THOMAS. 1990. Evaluation of the accuracy of ^{22}Na and tritiated water for the estimation of food consumption and fat reserves in passerine birds. Canadian Journal of Zoology 68: 1590–1594.

GERHART, K. L., R. G. WHITE, R. D. CAMERON, AND D. E. RUSSEL. 1996. Estimating fat content of caribou from body condition scores. The Journal of Wildlife Management 60: 713–718.

HALL, C. B., H. C. LUKASKI, AND M. J. MARCHELLO. 1989. Estimation of rat body composition using

tetrapolar bioelectrical impedance analysis. Nutrition Reports International 39: 627–633.

HAMMILL, M. O. 1983. The arctic fox, *Alopex lagopus*, as a marine mammal: physical condition and population age structure. M.S. Thesis, McGill University, Montréal, Québec, Canada, 72 pp.

HILDERBRAND, G. V., S. D. FARLEY, AND C. T. ROBBINS. 1998. Predicting body condition of bears via two field methods. The Journal of Wildlife Management 62: 406–409.

HUOT, J. 1988. Review of methods for evaluating the physical condition of wild ungulates in northern environments. Centre d'études nordiques, Université Laval, Québec, Canada, Nordicana No. 50, 30 pp.

———, AND G. PICARD. 1988. A simplified method for assessment of caribou body composition. The Journal of Wildlife Management 52: 606–609.

———, M.-L. POULLE, AND M. CRÊTE. 1995. Evaluation of several indices for assessment of coyote (*Canis latrans*) body composition. Canadian Journal of Zoology 73: 1620–1624.

JOPSON, N. B., J. M. THOMPSON, AND P. F. FENNESSY. 1997. Tissue mobilization rates in male fallow deer (*Dama dama*) as determined by computed tomography: the effects of natural and enforced food restriction. Animal Science 65: 311–320.

KISTNER, T. P., C. E. TRAINER, AND N. A. HARTMANN. 1980. A field technique for evaluating physical condition of deer. Wildlife Society Bulletin 8: 11–17.

KUSHNER, R. F. 1992. Bioelectrical impedance analysis: a review of principles and applications. The Journal of the American College of Nutrition 11: 199–209.

LEFEBVRE, C. 1998. Variations annuelles de la composition corporelle et des hormones de la reproduction chez le renard roux (*Vulpes vulpes*). M.Sc. Thesis, Université Laval, Québec, Canada, 59 pp.

LUKASKI, H. C. 1987. Methods for the assessment of human body composition: traditional and new. American Journal of Clinical Nutrition 46: 537–556.

MILLER, M. E. 1962. Guide to the dissection of the dog. 3rd Edition. Edwards Brothers Inc, Ann Arbor, Michigan, 369 pp.

OUELLET, J.-P. 1992. Ecology of an introduced caribou population on Southhampton Island, N. W. T., Canada. Ph.D. Thesis, University of Alberta, Edmonton, Alberta, Canada, 123 pp.

PACE, N., L. KLINE, H. K. SCHACHMAN, AND M. HARFENIST. 1947. Studies on body composition. IV. Use of radioactive hydrogen for measurement in vivo of total body water. The Journal of Biological Chemestry 168: 459–469.

PETERSON, R. O. 1977. Wolf ecology and prey relationships on Isle Royale. National Park Service Scientific Monograph Series. No. 11, U.S. Department of the Interior, Washington, DC, 210 pp.

PETHIG, R. 1979. Dielectric and electronic properties of biological materials. John Wiley and Sons, Chichester, UK, 376 pp.

POULLE, M.-L., M. CRÊTE, AND J. HUOT. 1995. Seasonal variation in body composition of eastern coyotes. Canadian Journal of Zoology 73: 1625–1633.

PRESTRUD, P. AND K. NILSSEN. 1992. Fat deposition and seasonal variation in body composition of arctic foxes in Svalbard. The Journal of Wildlife Management 56: 221–233.

RANDALL, E. L. 1974. Improved method for fat and oil analysis by a new process of extraction. Journal of the Association of Official Analytical Chemists 57: 1165–1168.

RINEY, T. 1955. Evaluating condition of free-ranging red deer (*Cervus elaphus*), with special reference to New Zealand. The New Zealand Journal of Science and Technology 36: 429–463.

ROBBINS, C. T. 1989. Wildlife feeding and nutrition, 2nd Edition. Academic Press, San Diego, California, 352 pp.

ROBY, D. D. 1991. A comparison of two noninvasive techniques to measure total body lipid in live birds. The Auk 108: 509–518.

SAS. 1987. SAS user's guide: Statistics, version 6. SAS Institute Inc., Cary, North Carolina 1028 pp.

SHENG, H.-P. AND HUGGINS, R. A. 1971. Direct and indirect measurement of total body water in the growing beagle. Proceedings of the Society for Experimental Biology and Medicine 137: 1093.

———, AND ———. 1979. A review of body composition studies with emphasis on total body water and fat. The American Journal of Clinical Nutrition 32: 630–647.

TORBIT, S. C., L. H. CARPENTER, R. M. BARTMANN, A. W. ALLDREDGE, AND G. C. WHITE. 1988. Calibration of carcass fat indices in wintering mule deer. The Journal of Wildlife Management 52: 582–588.

TREMBLAY, J.-P., M. CRÊTE, AND J. HUOT. 1998. Summer foraging behaviour of eastern coyotes in rural versus forest landscape: a possible mechanism of source-sink dynamics. Écoscience 5: 172–182.

VAN LOAN, M. L., AND P. MAYCLIN. 1987. A new TOBEC instrument and procedure for the assessment of body composition: use of Fourier coefficients to predict lean body mass and total body water. The American Journal of Clinical Nutrition 45: 131–137.

VOLTURA, M. B., AND B. A. WUNDER. 1998. Electrical conductivity to predict body composition of mammals and the effect of gastrointestinal contents. Journal of Mammalogy 79: 279–296.

WALSBERG, G. E. 1988. Evaluation of a nondestructive method for determining fat stores in small

birds and mammals. Physiological Zoology 61: 153–159.

ZUERCHER, G. L., D. D. ROBY, AND E. A. REXSTAD. 1997. Validation of two total body electrical conductivity (TOBEC) instruments for estimating body composition of live northern red-backed voles *Clethrionomys rutilus*. Acta Theriologica 42: 387–397.

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