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Additional indices to estimate fat contents in fisher *Martes pennanti* populations

Jean-François Robitaille & Kevin Jensen

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In order to develop more practical indices of fat contents in fisher *Martes pennanti* populations at a large scale, the relationship between individual discernable fat depots (popliteal, sternal, omental, mesenteric and perirenal) and fat percentage (PFAT) was examined in male and female skinned carcasses obtained from trappers in northeastern Ontario from the 1998/99 and 1999/2000 fur harvest seasons. PFAT differed significantly between sex/age classes ($F = 10.17$, $P < 0.0001$). In a development group (86 males and 86 females), PFAT was well predicted by each of the five potential fat indices common to both males and females. During the test phase (87 males, 93 females), estimated fat contents (%) based on either fat depot did not differ from observed PFAT neither in males nor in females ($0.05 < \text{paired } t < 1.33$, $0.19 < P < 0.71$). All models detected animals with lower fat levels, a useful feature for conservation applications. The accuracy of almost any of the five depots appears adequate to detect changes in fat levels in harvested fisher populations. This contrasts with other mustelids such as martens *Martes americana* where lower fat levels restrict the availability of discernable fat depots.

Key words: energetics, fat depots, fat index, fisher, nutritional condition

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Following Brown & Lasiewski's (1972) landmark paper on mustelid metabolism and body shape, it is commonly assumed that the slim-bodied mustelids are correspondingly lean. However, it has since been observed that the fisher *Martes pennanti*, among others, possesses substantial subcutaneous fat, which can result from the partic-

ular fat dynamics in this species (Garant & Crête 1999). The assessment of nutritional condition may also help detect source-sink contrasts where available habitats contrast in suitability.

The traditional study of body composition (i.e. water, protein and fat) allows assessing the health and nutri-

tional status within a population (Winstanley et al. 1998, Garant & Crête 1999), and such a comprehensive, laboratory-based approach obviously is most informative about fat dynamics and welfare of animals; it has, however, limited applications at a large scale. This has stimulated growing interest for the development of condition indices focused on fat contents (Virgl & Messier 1993, Garant & Crête 1999). There is probably no single valid method of measuring nutritional condition, but in active predators such as mustelids, body fat has attracted more attention as an energy source (Allen 1976, Lochmiller et al. 1985, Buskirk & Harlow 1989, Halfpenny & Ozanne 1989, Holand 1992, Pond & Ramsey 1992, Caughley & Sinclair 1994, Robitaille & Cobb 2003). Fat levels are related to life expectancy and fitness, as evidenced from starving animals usually having exhausted their lipid reserves (DeCalesta et al. 1975); organisms capable of storing energy reserves are assumed to have a selective advantage, especially when energy demands are high and energy intake does not meet short-term needs (Buskirk & Harlow 1989). From a management perspective, the ability to detect trends in nutritional condition will help monitor animal populations on a long-term basis (Robitaille & Cobb 2003). If the protocol remains simple, it should allow processing larger sample sizes to increase the resolution necessary to analyze and compare spatial or temporal trends in populations/cohorts where appropriate. With harvested furbearers, large numbers of carcasses can be accessed and analyzed for/by management agencies.

Relatively few studies have examined fat dynamics in mustelids, and some studies have used fat depots to analyze nutrition levels in wild populations (Clem 1977, Rego 1984). Internal fat depots were studied by Buskirk & Harlow (1989) and by Robitaille & Cobb (2003) as valid indices of fat levels in martens *Martes americana*. In fishers from Maine, Rego (1984) reported a correlation between a variety of condition indices and mesenteric fat. Variations in mesenteric fat contents in Ontario fishers were also observed by Clem (1977) in a short time-frame (November-December). Abdominal (Coulter 1966), renal and omental fat (Kuehn 1989) were also proposed as indices of body fat in fishers. Garant & Crête (1999) developed regression models that estimated total body fat, water and protein levels of fishers from southern Quebec. Fishers are known to accumulate significant amounts of fat compared to, for instance, marten (J-F. Robitaille, pers. obs.), and since fishers are larger, we suspected that there were, and therefore wished to develop possibly more practical fat indices based on macroscopic isolated fat depots, while testing those already established (Garant & Crête 1999).

The objective of our study was to develop and test various fat indices in wild fishers of north-central Ontario. Specifically, based on the relationship between selected macroscopic fat depots and body fat contents, we propose a selection of regression-based models that predict best the relative amount of body fat of fishers, and test the accuracy of selected functions on an independent fisher population.

Material and methods

Specimen collection

In total, 394 skinned fisher carcasses were collected immediately after the fur harvests of 1998/99 and 1999/2000 from registered trap lines on Manitoulin Island (46°N, 81°W; N = 181) or in the French River area (46°N, 80°W; N = 212), Ontario (1 unknown) and frozen until time of dissection (< 6 months at -18 °C). Known capture dates (N = 348) spanned between 25 September and 27 February. Carcasses were thawed in random batches at room temperature, sexed and retained for this study if carcass condition was good (i.e. no apparent freeze burns, no missing portions from skinning or scavenging) and the data set was complete (N = 363). Gastro-intestinal tracts were emptied, the carcass was weighed (skinless carcass mass, SCM) using either, or both, a Pesola™ scale (± 100 g) and a Sartorius™ scale (± 0.01 g) based on availability, and heads were removed for separate studies. Fishers were aged as either juvenile (< 1.0 year old) or adult (> 1.5 years old) based on the occlusion of the pulp cavity of one lower canine (Kuehn & Berg 1981, Dix & Strickland 1986) and, where necessary, on temporal muscle coalescence (Poole et al. 1994, Cobb 2000). The resulting sex/age samples were 117 juvenile males, 60 adult males, 106 juvenile females and 80 adult females.

Choice of potential fat indices

The choice of test indices was based on the distribution of various fat depots in Carnivora (Pond & Ramsay 1992, Pond et al. 1992) and in martens (Robitaille & Cobb 2003), preliminary observations of fisher carcasses, and the good definition of boundaries of individual depots. Abdominal fat depots included, from most to least superficial, a) the popliteal fat mass (PopFM) found posterior to the femurs, starting at the knee and bordered by the biceps femoris and the semi-tendinosus, b) the sternal fat mass (SFM), a v-shaped deposit of adipose tissue located at the base of the sternum beneath the abdominal muscles, c) the omental fat mass (OFM) represented by the greater omentum, d) the mesenteric fat

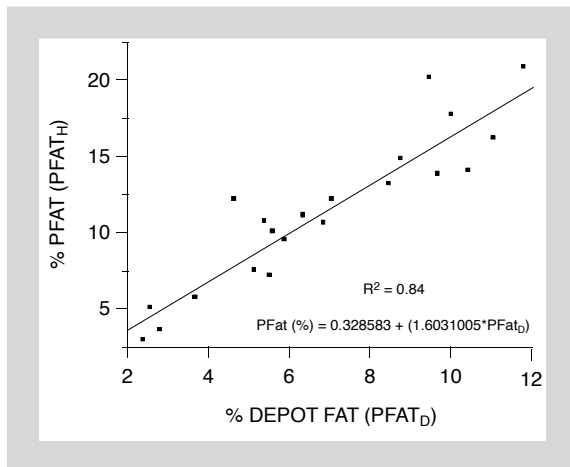


Figure 1. Predictive model of the overall fat contents (in %; PFAT_H) obtained from fat extraction procedure on 22 fishers (10 males and 12 females; PFAT_H), relative to the fresh mass of five discernable fat depots (sternal, popliteal, omentum, mesentery and perirenal) combined (PFAT_D).

mass (MFM) represented by the mesenteries attached to the intestines after removing the central vascular node, and e) the perirenal fat mass (PeriFM) surrounding each of the kidneys and extending along the dorsal wall of the abdominal cavity into the pelvic region. Each fat depot (i.e. pair in popliteal) was carefully dissected and its fresh mass was weighed using the Sartorius™ scale

(capacity: 3,100 ± 0.01 g). The fresh, rather than dry, masses of fat depots were selected as potential estimators of percent body fat. Considering the relatively large body size of fisher, the relatively good condition of carcasses and the fact that all depots but the PopFM were internal (thus less exposed to dehydration), the variability in water contents was deemed minimal. The use of fresh mass would simplify the use of the index.

General procedure followed that described by Robitaille & Cobb (2003) on martens, but given the large number of specimens, we used fat depot mass as an initial measure of fat contents (PFAT_D). We then extracted non-structural fats (PFAT_H using petroleum ether with 20 g samples of fisher dry homogenate (see Robitaille & Cobb 2003 and Cobb 2000 for details). We compared PFAT_D and overall fat contents obtained from whole-body extraction (PFAT_H) in 22 fishers (10 males, 12 females) randomly chosen. We thus obtained a PFAT corrected for subcutaneous (and other pervasive) fat using the function between PFAT_D and the total fat contents (PFAT) of the same animals obtained from whole-body fat extraction (Fig. 1).

Nutritional condition index development

In developing regressions, sexes were treated separately due to high sexual dimorphism in body size. Possible effect of age on PFAT_D was also examined, but assumed

Table 1. Univariate regression models relating percent body fat to various measurements of fat depots (all from fresh mass) of 86 male and 86 female fishers in northern Ontario. Italics are used for indices common to both sexes. *** = P < 0.0001.

Depot	Transformation	Intercept	SE	Slope ^a	SE	R ²	F	P
Males								
<i>Omentum</i>	% ^b	0.0144569	0.449	3.8276972	0.196	0.82	382.36	***
<i>Perirenal</i>	Log 10	-4.6444540	0.841	8.4821318	0.538	0.75	248.46	***
<i>Popliteal</i>	%	2.1021384	0.561	14.4128870	1.209	0.63	142.14	***
<i>Mesentery</i>	none	2.2366431	0.470	0.1898141	0.014	0.70	197.66	***
<i>Mesentery</i>	%	2.0781820	0.498	6.6952789	0.494	0.69	183.44	***
Omentum-mesentery	none	1.1264653	0.461	0.0668700	0.004	0.77	278.58	***
Omentum	none	1.9475004	0.538	0.0845300	0.007	0.66	161.99	***
Omentum-mesentery	%	-0.5011450	0.339	2.8415448	0.103	0.90	754.57	***
Sternal	Log 10	-0.5424780	0.644	10.2133730	0.711	0.71	206.59	***
Popliteal	Log 10	2.4364200	1.232	9.5052782	1.065	0.49	79.72	***
Females								
<i>Omentum</i>	%	0.3816210	0.020	0.2280577	0.010	0.87	543.94	***
<i>Perirenal</i>	Log 10	0.1133118	0.025	0.5694426	0.022	0.91	804.16	***
<i>Popliteal</i>	%	0.4963655	0.026	1.0778737	0.083	0.67	168.44	***
<i>Mesentery</i>	none	0.3613055	0.038	0.0313635	0.003	0.64	147.67	***
<i>Mesentery</i>	%	0.3123132	0.042	0.6647664	0.054	0.65	153.64	***
Perirenal	%, Log 10	0.8419129	0.006	0.5994392	0.019	0.92	1012.89	***
Popliteal	none	0.5166225	0.026	0.0524913	0.004	0.66	161.71	***
Omentum-mesentery	Log 10	-0.7890800	0.058	0.9591258	0.035	0.90	759.07	***
Omentum-mesentery	%, Log 10	0.3973527	0.012	1.0582773	0.028	0.95	1448.61	***

^a Slope differences between sexes is due to the use of LogPFAT with females.

^b Percent depot fresh mass over ingesta-free body mass.

to be accessory; juvenile fishers have nearly reached adult size at the time of harvest (Douglas & Strickland 1987, Frost 1994). Given the balanced representation of all sex/age classes in each region and years, the sample was pooled to increase its size and study the widest range of fat levels possible.

The sample was split into a development set ($N = 182$; 89 males and 93 females minus truncations) to build a regression function between each candidate index (fat depot) and PFAT, and a second set ($N = 181$; 88 males and 93 females minus truncations) to test the derived functions with an independent group of animals. Model functions were obtained from separate least squares linear regression of selected depots against PFAT. In order to obtain homoscedasticity and normality, the development groups of males and females were truncated from as few outliers as possible and transformed where necessary. Results include functions from normalized data using fresh mass, its proportion to fresh, ingesta-free body mass (e.g. %PopFM) or log-transformed variables (Table 1).

In the test phase, estimated percentage fat values ($PFAT_E$) were calculated using the functions, and their distribution compared with that of fat levels (PFAT) using paired t-test and univariate statistics. Statistical analyses were run using JMP v. 3.2 (SAS 1995), and data are presented as means \pm standard error.

Results

The relationship between $PFAT_D$ (based on depots alone) and PFAT from whole-body homogenates was strong and significant ($r^2 = 0.848$, $P < 0.0001$; see Fig. 1):

$$PFAT = 0.328583 + 1.6031005 PFAT_D \quad (1).$$

Equation (1) was used to obtain PFAT estimates for the fishers.

In the development group ($N = 86$ males, 86 females), males were on average 82% larger than females (SCM: males $3,467 \pm 59$ g; females $1,902 \pm 20$ g). PFAT ranged nearly ten-fold in both sexes (males: $8.4 \pm 3.0\%$; females: $6.9 \pm 1.7\%$), and was significantly higher in males than in females ($t = 3.55$, $P < 0.001$) as well as different among sex/age classes ($F_{3,172} = 10.17$, $P < 0.001$). In both sexes, juveniles had significantly higher PFAT levels than adults (males: $9.0 \pm 0.4\%$, $N = 56$ vs $7.1 \pm 0.5\%$, $N = 30$; $t = 2.94$, $P < 0.01$; females: $7.7 \pm 0.4\%$, $N = 50$ vs $5.9 \pm 0.4\%$, $N = 36$; $t = 3.11$, $P < 0.01$).

In each sex, the fresh mass of most fat depots had a skewed distribution that required transformation (see

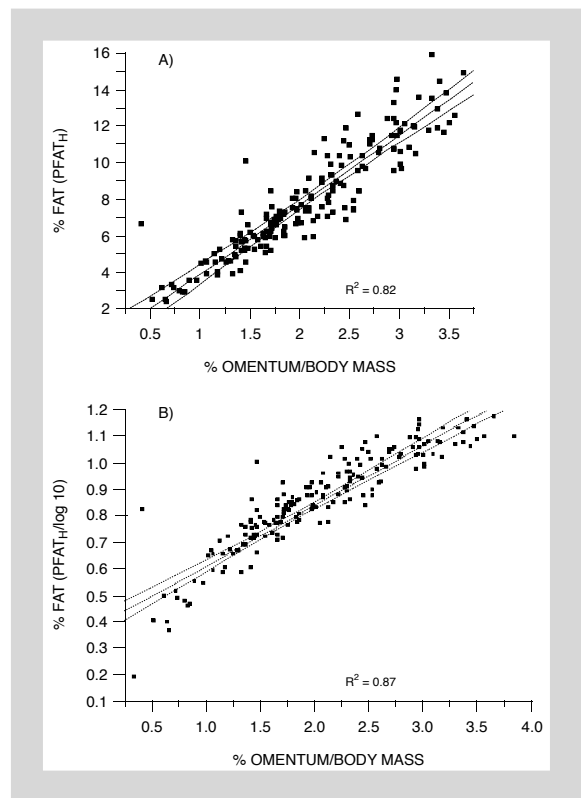


Figure 2. Regression models between fat contents (PFAT) in fishers and the relative fresh mass of omentum (% omentum) in males (A; $N = 86$) and females (B; $N = 86$).

Table 1). Screening for candidate variables (for each sex) consisted of attempting normalization by a) using the depot mass relative to body mass (in %), b) truncation of a few individuals or c) log 10 transformation, and retaining only the normalized variables. This resulted in five fat indices common to both sexes (e.g. % omentum; Fig. 2) and additional indices for each sex (see Table 1). PFAT was generally better predicted in females than in males (see Table 1). Percent omentum performed better than other depots with males and females ($r^2 = 0.82$ and 0.87 , respectively). Another strong index was the combination of omentum and mesentery relative masses (% in males, log 10 in females; see Table 1). In females, log 10 perirenal mass was the strongest predictor of fat levels in the individual. Except possibly for PopFM in both sexes, differences in variance explained were considered negligible (see Table 1).

The test group (88 males minus one truncation and 93 females) showed similar fat values and trends between sexes (males: $x = 8.10 \pm 0.36\%$; females $x = 7.13 \pm 0.27\%$), and revealed that despite lower performance, all five indices common to both sexes predicted fat con-

Table 2. Univariate statistics of actual and estimated fat contents in a test fisher population of 87 males and 93 females. Significance was obtained using paired t-test between PFAT and fat index estimate.

PFAT index	Males					Females				
	X	SE	Min	Max	Significance	X	SE	Min	Max	Significance
PFAT	8.10	0.36	2.45	15.75	--	7.13	0.27	1.95	15.54	--
% Omentum	7.91	0.31	2.45	14.34	ns	7.01	0.29	3.04	16.87	ns
LogPerirenal	8.30	0.27	1.96	14.79	ns	7.13	0.26	2.22	14.43	ns
% Popliteal	8.10	0.32	3.02	15.67	ns	6.89	0.30	3.26	22.78	ns
Mesentery	8.24	0.22	3.89	14.31	ns	7.11	0.38	2.63	35.58	ns
% Mesentery	8.41	0.24	3.72	14.86	ns	7.04	0.33	2.41	28.76	ns

tents accurately compared to actual PFAT. Paired t-test confirmed that there were no differences between PFAT and PFAT_Es using any of the five fat depots (Table 2).

Discussion

Fishers were found to carry substantially more fat than martens of the same area (Robitaille & Cobb 2003), and this has implications for the fat dynamics in the species. In particular, fishers seem to depart from the typical body profile of smaller mustelids as it had a substantial portion of subcutaneous fat layer.

The relatively high fat contents, as well as the larger body size, of fishers have implications on the number of dissectable indices that can be found and can accurately predict individual fat levels. We reported here on five different fat depots that accurately predict fat levels, and this contrasts with martens where fewer depots are large enough to be located and measured. Also, the larger size of fishers allows easier (i.e. more precise) dissection, but also provides a protection against dessication of fat depots, thus allowing the use of fresh mass rather than dry mass of fat depots, a valuable time saver.

We also made an attempt at characterizing the ample subcutaneous layer of fat on the animals and develop an index such as inter-scapular fat depth in fox (Winstanley et al. 1998). Since fishers possess only a thin layer of fat in that body region, our measurements (in mm) were imprecise, yielded nearly constant values and were not repeatable. An ordinal (i.e. semi-quantitative 1 = little or no fat, to 3 = large amounts in inguinal and dorso-lateral regions) subcutaneous fat variable was used, but we found these data to be of limited use for documenting absolute fat contents of the animal. We found significant differences in fat contents of fishers with ordinal value of subcutaneous, suggesting that the subcutaneous layer varied somewhat proportionally to overall fat levels. The relationship shown between depot fat and complete fat levels further confirmed this linear relationship.

Most depots performed better when corrected for body size, which varied nearly two-fold in each sex. In this study, we assumed that fat dynamics may be affected by factors other than body size such as sexual roles and preferred to provide separate estimators for each sex.

Some depots such as perirenal had a second order relationship with PFAT requiring their transformation. As with martens (Robitaille & Cobb 2003), it appears that some depots (i.e. log 10 transformed) increased disproportionately to the overall fat contents of the animal. We suggest that the fat in this region, which included fat surrounding ovaries, may be serving a second function as specific energy reserves for reproductive tract. Alternatively, these depots may contain more non-fat tissue with age (Buskirk & Harlow 1989).

Our study confirms the suggestion that percent omentum fresh mass is a performant fat index of fisher fat that will detect values ranging within 3-15% fat. Omentum has been repeatedly proposed as a reliable fat index (Buskirk & Harlow 1989, Garant & Crete 1999). The main thrust of our study was to build upon previous work and reveal the potential of relatively easy fisher fat indices for large-scale applications. To that extent, it appears that a) the sternal depot (log 10) performs well with males, while the popliteal fat depot (log 10 in males) appears as a satisfactory predictor with both sexes.

Because fat depots were included in PFAT values, larger assemblages of fat depots correlated well with PFAT (e.g. omentum + mesentery), however, small depots (sternal, popliteal) performed surprisingly well, probably in part because of their fine delineation and dissection, but mostly due to their consistent relationship with overall fat contents.

Some studies recommended the use of depot dry mass (Robitaille & Cobb 2003), but using fresh mass simplifies the index in its measure by the general practitioner in large-scale studies. Fisher carcasses have lower surface-to-volume ratios hence are less vulnerable to dehydration (J-F. Robitaille, pers. obs.) than smaller-sized mustelids (Greer 1968, Robitaille & Cobb 2003). Also, trappers volunteered carefully bagged specimens and car-

casses < 6 months post-capture. Fresh mass should thus only be used under those conditions and for full-grown fishers. With martens, Robitaille & Cobb (2003) suggested using omentum (dry mass) as a fat index for both males and females primarily because of the variable condition of the carcasses (J-F. Robitaille, unpubl. data).

In this study, the variance explained was relatively high for each tested index. One complication was the skewed frequency distributions of most fat depots, as well as PFAT in females: male and female fishers ranged lower in fat values, with a few higher values in all sex/age groups. This required data transformation.

In this empirical study, we have used wild animals caught mostly during November and December when fur quality is considered prime. We acknowledge the possibility of seasonal variation of fat levels, but we trust that the functions provided can accurately predict a wide range of fat levels because they were based on a large sample size. Our results show that the functions predicted well minimal (ca 3%) as well as maximal fat levels (ca 15%).

In conclusion, we have observed that fishers distribute their fat reserves proportionally in several discrete fat indices, including a subcutaneous layer, in popliteal areas, as well as in four different areas of the abdominal cavity. This is in contrast with fat dynamics of leaner, smaller mustelids such as martens. In the context of harvested fisher populations of northern Ontario, changes in the fat contents in fisher populations can be detected using a fat index based on the fresh mass of at least five different fat depots. We acknowledge the possibility that fat dynamics of fishers may vary with population densities in unexploited populations, prey availability, and temperature regimes, and look forward to seeing comparable fat indices used to explore the effects of these ecological parameters at large geographical scales.

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